THE NUTRITION OF LAMBS OFFERED FORAGE BRASSICAS

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I hereby declare that I have composed this thesis myself, and, except where otherwise stated, the work contained herein is my own.

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If you cry out for insight
and raise your voice for understanding
if you seek it like silver
and search for it as for hidden treasures;
then you will understand the fear of the Lord
and find the knowledge of God.
For the Lord gives wisdom;
from his mouth comes knowledge and understanding;

Proverbs 2 3-6

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LIST OF ABBREVIATIONS

ADF	acid detergent fibre
ADL	acid detergent lignin
C	centigrade
Ci	curie
cm	centimetre
DM	dry matter
DOMI	digestible organic matter intake
g	gramme
h	hour
ha	hectare
kg	kilogram
kJ	kilojoule
l	litre
M	molar
ME	metabolisable energy
mg	milligramme
ml(s)	millilitre(s)
min(s)	minute(s)
mol	mole
N	nitrogen
NDF	neutral detergent fibre
NPN	non protein nitrogen
OM	organic matter
r.p.m.	revolutions per minute
S	sulphur
SMCO	S-methyl-cysteine sulphoxide
t	tonne
VFA	volatile fatty acids
W	liveweight

ABSTRACT

The nutritive value of a range of forage brassicas to lambs was described and the results used to test the extent to which the supply of nutrients from forage brassica crops could be increased and animal performance improved by supplementation. Some of the factors influencing the voluntary intake of forage brassicas by lambs were also investigated.

The voluntary intake of OM of cabbage leaf, hybrid turnip leaf, stubble turnip leaf and bulb, rape leaf and stem, kale leaf and stem and swede bulb were found to range from 17 to 24 g OM kg^{-1} W day^{-1} with uniformly high level of digestibility of OM (0.77 to 0.94). The amounts of OM apparently digested in the rumen per kg OM and kg DOM intake were in the range 0.54 to 0.73 and 0.67 to 0.79 respectively, higher than those reported previously for other forages. Non-ammonia nitrogen flows at the abomasum ranged from 0.66 to 1.33 g N g^{-1} N intake. It was estimated that tissue gains in lambs grazing the bulb components were limited by the availability of nitrogen substrates in the rumen, whereas in lambs grazing the leaf and stem components, tissue gains were limited by the availability of energy substrates in the rumen.

This latter hypothesis was tested by giving energy and energy/protein supplements to lambs offered leaf components of rape and hybrid turnip leaf under restricted intake in an indoor study and by conducting a grazing experiment. Supplementation with a barley supplement as 25% of the diet increased the NAN flow at the abomasum by 30% in lambs given hybrid turnip but not in lambs given rape leaf. Supplementation also resulted in a 10% increase in the proportion of digestible OM apparently digested in the rumen with both crops. The results were interpreted as indicating that NAN flows at the abomasum

were indeed limited by energy substrates in the rumen, the lack of response with rape leaf being attributed to the method and type of supplement not being optimum for the capture of the N potentially available in the rumen.

Under grazing conditions, the substitution rates of rape leaf and hybrid turnip leaf by supplements ranged from 0 to 0.4 g OM forage g^{-1} OM supplement intake. Lambs grazing hybrid turnip had lower intakes and carcase gains than lambs grazing hybrid turnip, but when supplemented, carcase gains were similar to those of lambs grazing rape leaf. The fat content of the carcase with lambs grazing hybrid turnip, irrespective of supplement treatment, was lower than that of lambs grazing rape leaf.

The voluntary intakes of rape leaf were not found to be influenced by the presence of foam in the rumen or by the presence of additional tactile stimuli on the rumen wall. The infusion of aglucone products of sinigrin, the principal glucosinolate present in cabbage, into the rumen of lambs given a cabbage diet resulted in variable voluntary intakes. These findings suggested that glucosinolates may be involved in the low and variable intakes associated with forage brassicas.

CHAPTER 1 - INTRODUCTION

Since their introduction to Britain in the late 17th century, forage brassicas have constituted a major part of the winter feed available to livestock in the UK, supplementing the poor quality grass available at this time. However, this century has seen a dramatic decline in their popularity with the proportion of tillage devoted to root and forage crops declining from 21 to 3 percent between 1908 and 1976 (Fitzgerald, 1983). Although these figures are probably an underestimate of the quality of forage brassicas sown (McFarlane Smith et al, 1984) because up to 80% of rape is sown after the June census has been completed. Less forage crops are being grown because of such factors as high labour requirements, the availability of alternative feeds and a lack of knowledge about the nutritive value of forage brassicas which have all been suggested as contributing to their decline in popularity (Fitzgerald, 1983). In recent years, however, this decline has slowed down, possibly as a consequence of the increased mechanism of forage brassica production (Lawrence, 1979).

Forage brassicas are primarily used in the autumn and winter to provide fodder to lambs that cannot be finished off grass. Approximately 40 percent of the lambs produced in the UK fit into this category (MLC, 1987). McFarlane Smith et al (1984), in a study of the husbandry practices of forage rape reported that over 80% of such crops were utilised for finishing lambs. Almost half of lambs produced by the UK sheep industry are from hill and upland type of farms (Eadie, 1984) which have limited resources for finishing lambs and rely on selling their lambs to be finished on lowground farms. The UK sheep industry is also expanding. Between June 1985 and December 1986 breeding ewe numbers increased from 13.9 to 16.7 million (MLC, 1987).

This will lead to the need to finish more lambs and this may lead to an increase in the area of land allocated to forage brassicas in the future.

Little research has been conducted on the nutritive value of forage brassicas for finishing lambs. The majority of research on forage brassicas has been concerned with assessing varietal characteristics (e.g. Bradshaw, 1981) or estimating yield under varying conditions (e.g. Harper and Compton, 1980). The only study describing in detail the nutritive value of a forage brassicas (Barry et al, 1984a) was concerned with forage kale grown in New Zealand. The principal purpose of this thesis, was therefore, to describe the nutritive value of a wide range of forage brassicas, suitable for growing under UK conditions. From this information, hypotheses could be formed and tested as to the possible factors affecting lamb performance on these crops, with the ultimate objective of being able to give more precise predictions of performance of lambs utilising forage brassicas.

CHAPTER 2 - REVIEW OF LITERATURE

Introduction (Section 2.1)

Forage brassicas are confined to three species within the Genus Brassicae; Brassica campestris L., Brassica oleracea L. and Brassica napus L. (McNaughton and Ross, 1978).

Brassica campestris L. contains the turnips, which have been classified into three main groups according to the colour of flesh and hardiness and the stubble turnips which constitutes a distinct type both in morphology and culture (McNaughton and Thow, 1972). Brassica oleracea L. contains the kales of which there are three types, the marrow-stem, thousand head, and dwarf thousand-head (Horne, 1966). The marrow-stem kale is the least frost-hardy type but improved varieties such as Maris Kestrel have been produced which are hardier and which have also been selected for high digestibility of stem (McNaughton and Ross, 1978). Brassica oleracea L. also contains the cabbages. Brassica napus L. contains the rapes and swedes. Varieties of rape are broadly classified into giant and dwarf types according to their height with giant and dwarf rapes having average heights of 80 and 50 cm respectively. (Horne, 1966). Swedes are grouped into three main types according to their skin colour purple, bronze and green, although eight distinct types of swedes have been recognised on the basis of skin colour and root shape and six types distinguished on root shape alone (McNaughton and Thow, 1972). Although swedes and turnips belong to different species, they are very similar both morphologically and chemically. For example, Kay (1971) noted that from a nutritional standpoint the differences between then were mainly in terms of DM content; 60 to 100 g DM

kg^{-1} for turnips and 80 to 120 g DM kg^{-1} for swedes. Similarly, rapes are closer in terms of their utilisation by ruminants to the kales than to

the swedes. The rapes and kales can be divided into the leaf and stem components when examined from a nutritional or utilisation viewpoint. This therefore gives three distinct classes of forage brassicas, viz those forage brassicas with a significant leaf component comprising rape leaf, kale leaf, cabbage and hybrid turnip leaf which have 0.8 of their DM as leaf material (Sheldrick et al, 1981) and stubble turnip, those forage brassicas with a high stem component, i.e. the stems of the rapes and kales, and those with a high bulb component, comprising the swedes, turnips and also stubble turnip bulbs.

In this review, the chemical composition, digestibility, voluntary intake, nutrient digestion and absorption of these three classes of forage brassicas for ruminants will be discussed. Performance of lambs and knowledge of supplementation of forage brassica crops will then be discussed together with the possible factors affecting performance by lambs. The objective of this review is, therefore, to identify those areas where a lack of knowledge of the nutrition derived from forage brassicas limits our ability to predict levels of performance of lambs and supplementation strategies.

Chemical Composition (Section 2.2)

The range of DM and ash contents reported in the literature for leaf, stem and bulb of forage brassicas are summarised in Appendix Table 2.1. Leaf components have DM contents ranging from 80 g DM kg^{-1} (cabbage, McDearmid (1978)) to 198 g DM kg^{-1} (turnip, Barry and Drew (1978)). The DM of stem components are normally towards the upper region of this range with values as high as 225 g DM kg^{-1} (rape, Jones (1959a)). However some kale varieties, for example Maris Kestrel, have lower DM contents around 150 g DM kg^{-1} for stem (Bradshaw and Borzucki, 1983). The DM content of the bulb components of the turnip

(62 g DMkg^{-1}, Dover (1980)) is generally lower than that of the swede (120 g DM kg^{-1}, Dodsworth (1956)). Compared to other succulent forages such as perennial ryegrass or white clover with DM contents in the range 132 to 338 g DM kg^{-1} (Gibb and Treacher, 1984; Armstrong et al, 1986), forage brassicas have a similar or lower DM content.

Several factors such as sowing date (Dibb and Brown, 1964) and plant density (Frame and Robinson, 1966), have been shown to influence the DM content in kale, presumably reflecting the physiological age of the plant. With swedes, higher latitudes and altitudes increase the DM content. Dodsworth (1956) attributed this to a shorter growing season prolonging the vegetative phase of growth and delaying lignification.

A large variation in ash content has been noted, presumably associated with variable soil contamination with a range of 60 to 150 g kg^{-1} DM found within species and within components. A narrower range of 90 to 130 g kg^{-1} DM has been observed for comparable autumn perennial ryegrass/white clover pasture (e.g. Barry et al (1978).

Cornforth et al (1978) compared the mineral content of swedes, turnips and kales with samples of mixed pasture and found that forage brassicas contained more Sulphur and Calcium and had wider Calcium: Phosphorus ratios than graminaceous herbages, whilst Phosphorus, Sodium and Molybdenum contents and Magnesium : Sulphur ratios were less. They also found that there was more Magnesium and Zinc present in swede and turnip leaves than in the herbage of grasses or kale. Kale also contained less Copper than comparable pasture samples. Barry et al (1981a) also found higher Calcium:Phosphorus ratios in kale compared to autumn pasture (perennial ryegrass/white clover) but found that trace element concentrations were similar to that found in the same pasture.

The variation in N concentrations in leaf, stem and bulb

components reported in the literature is given in Appendix Table 2.2. In general leaf components have a higher N content (range 22.1 to 43.8 g N kg^{-1} DM) than that found in stem (range 9.9 to 26.7 g N kg^{-1} DM) or bulb (range 14.2 to 31.0 g N kg^{-1} DM). Within the kale plant, similar N contents have been reported for upper stem and leaf (Jones, 1959b; Frame and Robinson, 1966) but lower concentrations have been recorded in the lower (hard) stem (Drew et al, 1974; Barry and Drew, 1978). Concentrations of N in the range 22 to 45 g kg^{-1} DM (e.g. McDonald et al, 1977; Barry et al, 1985) have been reported for ryegrass/white clover swards in the autumn and these are similar to the values reported for the leaves of forage brassicas. However, the amount of NPN as a proportion of total N is much lower in grass herbage than in forage brassicas (e.g. grass herbage - 0.10 to 0.20; forage brassicas - 0.24 to 0.46; Drew et al, 1974; Barry and Drew, 1978). Around 0.50 to 0.75 of the higher proportion of NPN:N in forage brassicas may be explained by their high concentrations of nitrates (10 - 20 g N kg^{-1} DM; Smith, 1980)).

In addition to having higher NPN concentrations, forage brassicas have lower N:S ratios than those found in pasture. Barry et al (1981a) reported a ratio of 12.3:1 for autumn pasture compared to 4.6:1 for kale leaf. The lower ratio has been attributed to the high concentration of sulphur-containing organic compounds, which will be discussed later in this review. It has also been shown that the N:S ratio in forage brassicas can be increased by cultural means, such as by growing kale in low S soils which reduces the S content in the plant but causes no change in total N content (McDonald et al, 1981; Barry et al 1984a).

The few reports of the NDF, ADF and ADL content of forage brassicas recorded in the literature are summarised in Appendix Table

2.3. Barry and his co-workers reported the content of structural and non-structural carbohydrates for the whole kale plant and from this data NDF content can be estimated as being in the range 170 to 190 g NDF kg^{-1} DM (Barry et al, 1982; Barry et al, 1984a; Barry et al, 1985). Barry et al (1984a) found that 0.56 of the structural carbohydrate was in the form of cellulose and 0.26 was in the form of hemicellulose. No estimates of NDF have been reported for other species, although ADF values in the range, 124 g ADF kg^{-1} DM (swede bulb, Partridge et al, 1985)) to 220 g ADF kg^{-1} DM (kale whole plant; Pelleter and Donefer, 1973) have been reported. As with NDF content, estimates of lignin concentration have only been made with the kale species and values in the range 28 to 59 g lignin kg^{-1} DM have been reported (Pelletier and Donefer, 1973; Barry and Manley, 1985).

As there is a paucity of data available on the structural carbohydrate content of forage brassicas, differences between and within forage brassicas cannot be assessed. The data of Bath and Rook (1965) showed that the leaf portion of the kale plant had a lower lignin content (13 g lignin kg^{-1} DM) than the whole plant (47 g lignin kg^{-1} DM). Such differences are also likely to exist between different components of other forage brassicas. In comparison to forage brassicas, autumn pasture has a much higher structural carbohydrate content (ADF range 313 to 362 g ADF kg^{-1} DM; Barry et al, 1984a; Barry et al, 1985), and contains proportionately less cellulose (0.43) but more hemicellulose (0.32).

The range of total sugar and water soluble carbohydrate content detailed in the literature is given in Appendix Table 2.4. The bulb components are generally higher than leaf and stem components. Values reported lie within the range, 321 g kg^{-1} DM (McNaughton and Thow,

1972) to 652 g kg^{-1} DM, Partridge et al, 1985), whilst those for leaf and stem components are in the range 167 to 527 g kg^{-1} DM (Bath and Rook, 1965; Partridge et al, 1985). The soluble carbohydrate content of forage brassicas is higher than that found in autumn pasture, e.g 121 g kg^{-1} DM (Barry et al, 1984a) and is a feature of forage brassicas.

In general, forage brassicas are characterised by low DM content, in the range 62 to 225 g DM kg^{-1}, with the stem components exhibiting the highest and the bulb components the lowest content. On a DM basis, forage brassicas have a similar N content (9.9 to 28.7 g N kg^{-1} DM) to ryegrass/clover swards but the amount of NPN as a proportion of total N in forage brassicas is higher. Forage brassicas are also characterised by low concentrations of structural carbohydrates (121 to 220 g ADF kg^{-1} DM) and high water-soluble carbohydate contents (167 to 652 g kg^{-1} DM), which in the bulb components is mainly in the form of glucose.

Digestibility (Section 2.3)

The relatively few measurements of the apparent digestibility of forage brassicas by sheep in vivo show high values for the digestibility of OM in the range 0.782 (rape stem; Armstrong, 1984) to 0.921 (swede bulb; Barry et al, 1971). Values reported in the literature for the apparent digestibility of DM and OM are summarised in Appendix Table 2.5. The digestibility of OM in vivo of the leaf components of rape (0.831) was found to be higher than that for the stem (0.782) (Armstrong, 1984), although Barry et al (1984a) observed similar values for kale leaf and stem of 0.883 and 0.877 respectively.

The in vitro digestibility of OM has been more widely measured and values for leaf, stem and bulb components are summarised in Appendix Table 2.6. Values for in vitro digestibility of OM for the leaf

components are in the range 0.790 to 0.926 whilst those for the stem components are generally lower in the range, 0.486 to 0.906. Values for in vitro digestibility of OM for the bulb components have not been reported but in vitro digestibility of DM is in the range 0.745 to 0.891. A feature of in vitro compared to in vivo digestibility data is their greater variability, presumably a function of biases in the in vitro digestibility method. In comparisons between in vitro digestibilities of rape leaf and stem, Fitzgerald (1984 and 1985) reported higher in vitro DM digestibilities in leaf than in stem and this was also found to be the case for marrow-stem kale (Jůlen, 1979). However the kale variety Maris Kestrel, was found to have similar in vitro digestibility values for both leaf and stem (Bradshaw and Borzucki, 1983).

The digestibility values for forage brassicas are higher than those reported for grass herbage. For example, the in vitro digestibility of OM for autumn pasture in New Zealand has been reported to be in the range 0.740 to 0.850 (Barry et al 1981b; Barry et al 1983a). Gibb and Treacher (1984) reported values in the range 0.750 to 0.807 for the in vitro digestibility of OM summer pasture grazed by lambs and Armstrong et al (1986) reported the in vivo digestibility of OM in the range 0.589 to 0.796 for perennial ryegrass grazed in the summer.

The high digestibilities of OM and DM associated with forage brassicas are generally attributable to a high content of soluble carbohydrates and low content of structural carbohydrates. Barry et al (1984a) found that the apparent digestibility of hemicellulose and celluiose in vivo was slightly higher for kale than for autumn pasture (hemicellulose 0.870 vs 0.832, s.e.= 0.0161; cellulose 0.865 vs 0.790, s.e.= 0.0243) and this, together with the higher concentrations of water-soluble carbohydrates, resulted in a higher apparent digestibility of energy for

kale than for autumn pasture (0.864 vs 0.729, s.e.= 0.0770). Similar apparent digestibilities of energy in vivo with kale diets have been reported by Pelletier and Donefer, (1973) and slightly higher apparent digestibilities of energy of 0.901 and 0.908 have been reported by Barry et al, (1971) for turnip and swede bulbs respectively, reflecting the high concentration of water-soluble carbohydrates present in these components. The apparent digestibility of crude protein in vivo has been reported to be 0.750 for rape (Greenall et al, 1958) and 0.836 for kale (Pelletier and Donefer, 1973). No data for other species has been reported.

In summary, there is a paucity of data relating to in vivo digestibility of DM, OM and structural carbohydrates of forage brassica components, with only four data sets being reported. More in vitro digestibility values are available but, since relationships between in vivo and in vitro digestibility values have normally not been established, it is not possible to draw firm conclusions. Nevertheless, forage brassicas are characterised by high digestibility coefficients, with the bulb components having higher apparent digestibilities than the leaf or stem. The higher water-soluble carbohydrate and lower structural carbohydrate content in all forage brassica components presumably account for the higher digestibility of forage brassica components compared to other herbage diets.

Voluntary Intake (Section 2.4)

Most of the few measurements of the voluntary intake of forage brassicas have been made in studies on freshly cut material offered to animals indoors. Daily voluntary intakes by lambs have been reported for kale (60.4 to 68.0 g DM kg^{-1} $W^{0.75}$; Pelletier and Donefer, 1973), rape leaf and stem (44.2 and 39.4 g DM kg^{-1} $W^{0.75}$; Fitzgerald 1977a,b).

In grazing experiments, intakes have been measured by methods based on the estimation of faecal output and predicting the indigestibility of the diet (Armstrong et al, 1984) and from pre- and post-grazing determinations of the standing crop (Fitzgerald and Black, 1984; Jagusch et al, 1977). These methods have given daily intakes in the range, 58 g OM kg^{-1} $W^{0.75}$ (rape; Armstrong et al, 1984) to 106 g DM kg^{-1} $W^{0.75}$ (turnip; Jagusch et al, 1977). However it is probable that the errors involved, particularly in the pre- and post-grazing standing crop method, contribute to a wider range of intakes than actually occurs. Fitzgerald and Black (1984) pointed out that this method is likely to lead to an overestimation of intake since leaves which have decayed or have been trampled into the soil are assumed to have been eaten. The method based on estimating faecal output and predicting indigestibility relies heavily on the in vitro determination of digestibility. As discussed previously values for the in vitro digestibilities of forage brassicas have been found to be variable.

Nevertheless, it is possible to conclude that intakes of lambs offered forage brassicas are generally lower than those of other herbages of high digestibility. Pelletier and Donefer (1973) related the voluntary intake of marrow-stem kale to that of alfalfa. They found that the voluntary intake of kale was proportionately 0.15 to 0.24 lower than that of the alfalfa. In addition, Barry et al (1982) reported the voluntary intakes of kale to be 0.18 lower than those of lucerne and Drew (1968) found a 0.20 reduction in voluntary intake by lambs offered swedes compared to lucerne hay.

Several factors have been suggested that may contribute to the lower intakes of leafy forage brassicas. These include low DM content (Bradshaw et al, 1982), nutrient imbalance (Drew, 1968) and sulphur-

containing compounds, particularly S-methyl-cysteine sulphoxide (SMCO) (Barry et al, 1982). Low DM or high water content has not been examined further but research on nutrient imbalance and the presence of sulphur-containing compounds will be discussed later in this review.

Under grazing conditions, additional factors may affect intake. Hodgson et al (1986) suggested that the canopy structure of leafy forage brassica may be involved in the low intakes observed. They cited evidence which indicated that biting rates on rape crops (7 to 29 bites min^{-1}) were substantially slower than those on grass (22 to 94 bites min^{-1}). Grazing times (330 to 600 mins day^{-1}) may also be shorter than those normally observed on grass (390 to 810 mins day^{-1}). However, as intakes are also low when crops are offered indoors in a chopped form, they concluded that ingestive behaviour was unlikely to be an important factor.

Barry et al (1981a) noted that there was a curvilinear relationship between level of daily herbage allowance of kale (Maris Kestrel) and predicted intake with an increase in apparent intake between the low (58 g DM kg^{-1} W day^{-1}) and medium (116 g DM kg^{-1} W day^{-1}) allowances but not between the medium and high (173 g DM kg^{-1} W day^{-1}) allowances.

The intake of bulb components by lambs may be limited by several other factors. Bastiman and Slade (1978) reported an increase in intake by lambs confined on a concrete pad outdoors and offered chopped swede bulbs compared to lambs folded on a similar crop in the field. They attributed this partly to reduced soil contamination of the chopped swedes. The size of the chopped material was also shown to be significant in affecting intake. Drew (1968) noted that lambs lost up to five of their milk teeth while grazing a crop of swedes and this may be

partly responsible for the differences in intake observed by Bastiman and Slade (1978).

Chemostatic feedback mechanisms such as those described by Baile and Meyer (1969) have also been suggested as limiting the intake of bulb components. Kay et al (1972) compared the voluntary intakes by sheep of swedes and potatoes offered in a chopped form indoors and observed a lower voluntary intake of swedes than that of potatoes when these feeds constituted 0.87 of the diet (the remainder being a barley-based concentrate). Potatoes have a broadly similar chemical composition to swedes, with high digestibility and low fibre content (Boever et al, 1983) but the storage carbohydrate of potatoes is starch rather than glucose. Glucose in swedes may be absorbed more rapidly from the digestive tract, thereby increasing the possibility of the induction of a feed-back mechanism limiting intake, although other reasons for the differences observed could be postulated.

In summary, the intakes of all forage brassica components, both indoors and under grazing conditions, are generally lower than would be expected for forages of high digestibility. The possible factors contributing to these low intakes have not been elucidated but may be characterised into three groups. These are (a) the factors associated with the chemical composition of the crop, such as DM content and sulphur-containing compounds, (b) those factors associated with the grazing of the crop, such as canopy structure and herbage allowance, and (c) those additional factors associated in particular with the bulb components, such as teeth loss and chemostatic feedback mechanisms.

Nutrient Digestion (Section 2.5)

Barry et al (1984a) has provided the only detailed information on the sites of digestion of forage brassicas. They reported values of 0.66

g OM apparently digested in the rumen per g OM intake and 0.73 when expressed on a digestible OM intake basis. These are higher than values reported for grass herbages. For example, Beever et al (1978) reported that in sheep offered autumn perennial ryegrass 0.45 g OM was digested in the rumen per g OM intake and Ulyatt and Egan (1979) reported values in the range 0.54 to 0.63 for ryegrass and leguminous herbages.

Barry et al (1984a) also found that the amounts of water-soluble carbohydrates, pectin and cellulose digested in the rumen were similar to that which would be predicted for the digestion of ryegrass and white clover (Ulyatt and Egan, 1979). However hemicellulose digestion in the rumen was lower than would be predicted for other forage diets and Barry et al (1984a) attributed this to the presence of SMCO in the kale diet. The significance of SMCO will be discussed later in this review.

Dove and McCormack (1986), using the nylon bag technique, estimated the degradability of N in the rumen of rape samples to be in the range 0.75 to 0.83. They suggested that the relatively high level of degradability of N may be a factor in limiting growth rates in lambs given rape diets, resulting in a restriction in post-ruminal amino-acid supply.

NAN flows at the duodenum of sheep given kale diets were found to be 0.72 g NAN per g N intake by Barry et al (1984a). Calculations from this estimated that protein absorption from the small intestine was proportionately 0.14 of ME intake, which Barry et al (1984a) reported was less than that calculated for diets of fresh perennial ryegrass and white clover (proportionately 0.20 of ME intake; MacRae and Ulyatt, 1974).

From the limited evidence available on nutrient digestion, it is suggested that the apparent digestion of OM in the rumen of sheep given

forage brassica diets is higher than found in other herbage diets. N degradability in the rumen is also high.

Lamb Performance (Section 2.6)

Lamb performance on forage brassicas has been measured either in terms of responses in liveweight or carcase weight. Liveweight changes have been found to be very variable ranging from losses of 40 g W day^{-1} (Slade, 1977) to gains of 250 g W day^{-1} (Fitzgerald, 1985) (see Appendix Table 2.7).

One of the major difficulties in interpreting the data on liveweight change is the errors and biases associated with its measurement. Changes in the weight of gut contents between weighings have been suggested as being a major factor contributing to the large variation in liveweight change. Attempts have been made to reduce this variation by measuring liveweights after a 24-hour fast (e.g. Barry and Drew, 1978; Barry and Manley, 1985). However, as Fitzgerald (1983) in his review of forage crops for lamb finishing pointed out, this is impractical where lambs have to be weighed in field experiments or where measurements are made frequently. Moreover, the weight of gut contents is only likely to be important in experiments where there are short measurement periods (e.g. 28 days), after which the size of the liveweight gain reduces the errors associated with the weight of gut contents. Fleece contamination by either soil or water can also lead to inaccurate measurements of liveweight change, although this can be overcome to some extent by feeding a harvested crop to lambs indoors (e.g. Fitzgerald, 1977a; Fitzgerald, 1977b).

Reports of losses in liveweight refer in particular to short initial grazing periods. For example, Barry and Drew (1978) found that with lambs grazing either turnip or swedes liveweight gains in the first three

weeks of grazing the crop were lower than those in the subsequent three weeks. Similar observations have been reported for lambs grazing kale during the first five weeks after introduction to the crop (Barry and Manley, 1985) and for lambs grazing rape during the first two weeks after introduction to the crop (Fitzgerald, 1985). However other experiments with kale (e.g. Barry and Drew, 1978; Fitzgerald and Black, 1984) showed no initial depression in liveweight gain during the first three to four weeks of grazing the crop. It is important to know whether the liveweight gain differences reported above are real or a consequence of the measurement errors.

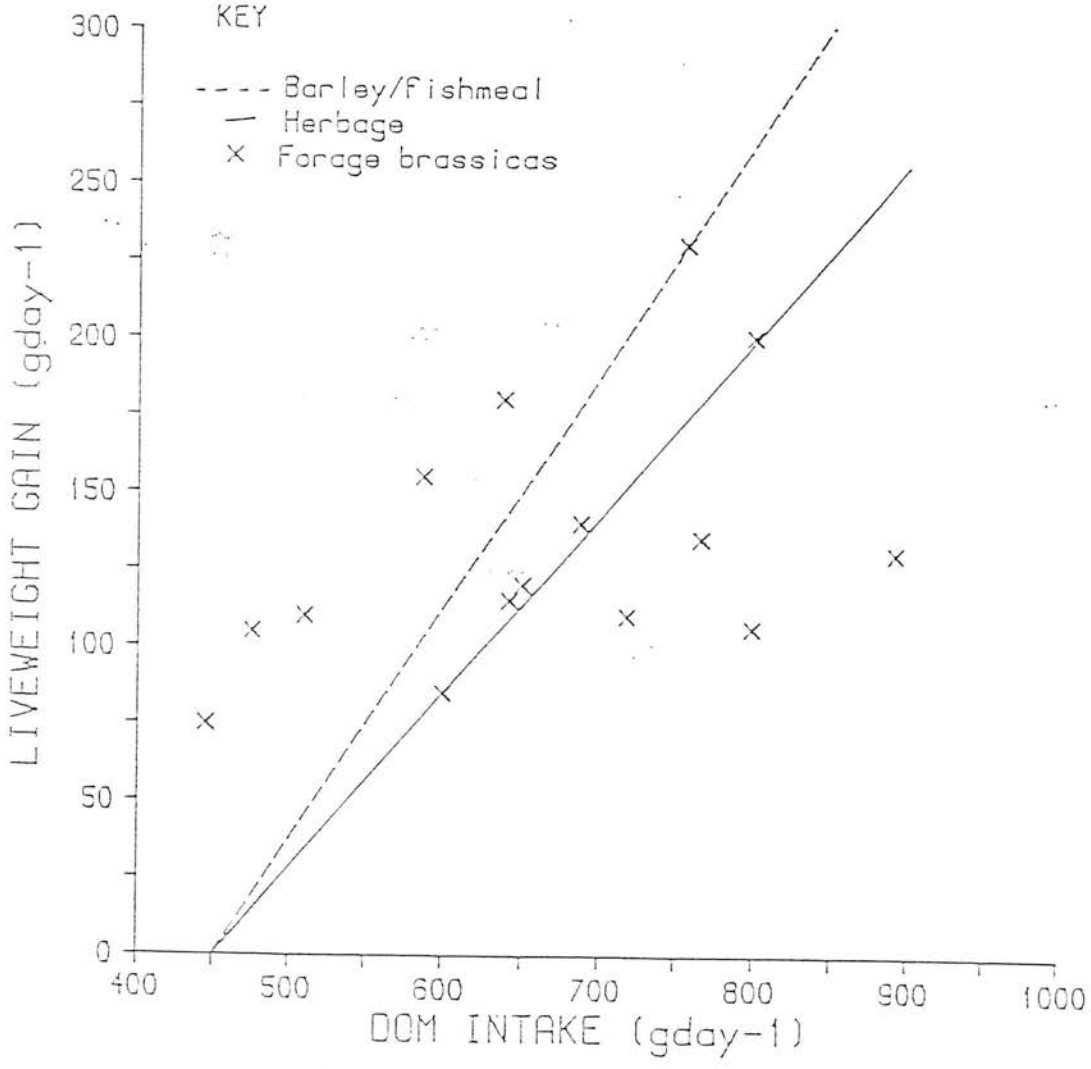
Most evidence suggests that liveweight gains for bulb crops are higher than for leaf crops. However between experiments there are considerable differences in the ranking of liveweight gains on different crops. For example, Scott (1971) reported that liveweight gains in lambs grazing turnips or swedes were higher than those grazing kale, whereas Drew et al (1974) found similar liveweight gains in lambs grazing these crops.

A more accurate, though less frequently used method of measuring animal responses to forage brassica crops, is carcase gain. Fitzgerald (1983) cited Fitzgerald (1970), where the ratio of carcase gain to liveweight gain averaged 0.75 but ranged from 1.10 after 26 days grazing rape to 0.68 after 67 days grazing rape. He suggested from this and similar observations in other experiments (e.g. Fitzgerald, 1969) that liveweight is not a very reliable indicator of lamb performance on forage crops particularly during the early stages, as most of the gain during the initial period is in the form of offal and not gain deposited in the carcase. This is confirmed by a later experiment (Fitzgerald, 1984) where the killing out percentage was significantly ($P < 0.05$) lower when

lambs grazing rape were killed on day 26 (42.3%) of the experiment compared to day 54 or 64 (43.7% and 43.2% respectively, s.e. = 0.03). Carcase gains, particularly during the initial measurement period, are therefore likely to be a more accurate measurement of performance than liveweight gains, as they are not subject to gut-fill and fleece-contamination errors. The main error likely to be associated with carcase gains is in the assumption made about initial carcase composition when using a companion set of lambs slaughtered at the start of the experiment. However Tulloh (1963) demonstrated that carcase body composition of sheep is closely related to its empty body weight, accounting for 88.3 to 96.1% of the variance. This suggests that the assumptions about initial liveweight of lambs would be accurate and therefore carcase gains would have lower errors associated with it than liveweight gains. There are only a few reports in the literature of daily carcase gains for lambs grazing forage brassicas, and these are presented in Appendix Table 2.7. The mean daily carcase gain over all crops was 61 g W day^{-1} (range 18 to 109 g W day^{-1}) and due to the paucity of data, no differences between different forage brassicas can be identified.

Compared to lambs of similar liveweight and age offered non-brassica diets, lambs ingesting forage brassica diets generally have lower liveweight and carcase gains. For example, liveweight gains in lambs of similar age and liveweight and offered pelleted lucerne or barley/white fish meal diets were in the range 188 to 386 g W day^{-1} (Ørskov and Grubb, 1979; Salman and Owen, 1981), whilst carcase gains of lambs grazing forage brassica crops have been observed to be in the range 81 to 104 g day^{-1} (Rutter, 1970; Doney, unpublished data). However, with lambs grazing autumn pasture, carcase gains of 94 g day^{-1} i.e. similar to those obtained from forage brassica crops, have been recorded (Jagusch et al, 1977).

FIGURE 2.1. The efficiency of utilisation of ingested OM in lambs offered barley/fishmeal concentrates, herbage diets or forage brassicas (after MacRae, 1976 and Hodgson et al, 1986).



Barry (1978) sought to explain the low liveweights and carcase gains, at least for swede diets, in terms of both low intakes and a reduced efficiency of feed utilisation for carcase gain. Drew (1968) suggested that the energetic cost of harvesting the crop *in situ* was higher for forage brassicas than for grass herbages. Barry *et al* (1971) estimated that 0.15 more digestible energy was required in raising the large volume of water, ingested when lambs grazed a turnip crop, to body temperature. They also estimated that digestible energy requirements for maintenance were 0.29 greater for sheep grazing forage brassicas than those grazing grass swards and concluded that this would lead to a reduction in the efficiency of feed utilisation for carcase gain. MacRae (1976) demonstrated that different relationships between DOM intake and LWG of lambs existed for different diets (see Figure 2.1). Hodgson *et al* (1986) related DOM intake to LWG in lambs grazing a variety of forage brassica diets. These have been included in Figure 2.1 by making the assumptions that the liveweight of the lambs was 30 kg and the apparent digestibility of OM of the forage brassica crops was 0.85. The spread of values of the data set suggests that, in general, the efficiency of utilisation of ingested OM from forage brassicas is similar to concentrate or pasture diets and, therefore, is probably not a major factor responsible for the low carcase gains. However, as most of the data sets reported by Hodgson *et al* (1986) related to leaf or stem rather than bulb components, it is possible that in lambs offered bulb components the efficiency of utilisation of ingested OM is lower.

Other possible factors which have been suggested as being responsible for the low tissue gains in lambs offered forage brassicas are low intakes, which have been discussed previously, the possible imbalance of nutrients, which will be discussed in relation to supplementation, and

the presence of sulphur-containing compounds, which is discussed in the next section.

In summary, both voluntary intakes and tissue gains in lambs offered forage brassicas have been shown to be lower than those of other herbages of high digestibility. Several factors have been suggested to account for the low intakes including low DM content, herbage allowance and difficulties in prehending the crop. From the limited data available it is suggested that the apparent digestion of OM in the rumen is higher in forage brassica diets than in herbage diets and that the degradability of N in the rumen is also high. A lower efficiency of utilisation of digestible OM with bulb components has been suggested as an explanation for the low carcase gains observed but there is little evidence to support such a conclusion for leaf and stem components. Possible reasons for the low intakes and tissue gains are the presence of sulphur-containing compounds and nutrient imbalances and these will now be discussed.

S-containing Compounds (Section 2.7)

In the review of the chemical composition of forage brassicas, the large concentration of non-protein N and S-containing compounds present was highlighted. Barry (1978) in reviewing factors governing the nutritive value of forage brassicas concluded that the fermentation products of SMCO and glucosinolates as NPN components were the most likely compounds to affect productivity. Barry (1978) indicated that the nitrates present would normally be reduced to ammonia in the presence of the high levels of soluble carbohydrates in the rumen. Any nitrite formed would be involved in converting haemoglobin to methaemoglobin but Barry (1978) concluded that generally this would not even be sub-clinically significant. SMCO and glucosinolates have, however, been

shown to adversely affect the health of lambs offered forage brassicas and these will be discussed below.

S-methyl-cysteine sulphoxide

It has been known for over 40 years that the feeding of kale was associated with ill health in ruminants and that the occurrence and severity of the symptoms could be reduced by limiting the intake of kale (Rosenberger, 1943). Clegg (1966) described kale-poisoning as characterised by haemoglobinurea, inappetance and weakness and in more severely affected animals by the acceleration of pulse and respiration rates and by a fall in milk yield. Haemotological changes included a fall in the haemoglobin content of blood, a fall in the red-blood-cell count and the appearance of reticulocytes and Heinz Ehrlich bodies. Later Greenhalgh et al (1969) found that non-ruminants were not affected by kale poisoning and that sheep were less severely affected than cattle. They also found that blood haemoglobin concentrations returned to normal when kale feeding was stopped. In a later experiment (Greenhalgh et al, 1970) it was established that the higher the proportion of kale in the ration, the more rapidly the animals became anaemic. However the cause of this anaemia was not known until Smith (1974) reported the involvement of SMCO in the anaemia. He discovered that SMCO breaks down in the rumen to dimethyl disulphide, which is absorbed into the blood, and causes a haemolytic anaemia. The formation of dimethyl disulphide was confirmed by later experiments (Earl and Smith, 1982; Barry et al, 1984b) and explains why kale poisoning was confined to ruminants and not other animals, such as rabbits or guinea pigs, in which dimethyl disulphide is not formed (Penny et al, 1964; Greenhalgh et al, 1969). The reason why cattle and goats are more susceptible to the anaemia than sheep, as observed by

Greenhalgh et al (1969), has not been determined.

Smith (1978) outlined the method by which dimethyl disulphide acts upon the erythocyte. The dimethyl disulphide combines with the erythocyte reduced glucothione (GSH), thus lowering the reducing environment within the erythocyte. This leads to the concomitant formation of Heinz bodies, described by Steven et al (1981) as depositions of methaemoglobin erythrocytes and methaemoglobin. These Heinz bodies are then excreted in the urine leading to haemoglobinurea and anaemia, which are the main symptoms, together with Heinz body formation, of SMCO action in ruminants. Concentrations of SMCO in the range 4.1 to 16.8 g kg^{-1} DM have been reported for forage brassicas (e.g. Whittle et al, 1976; Bradshaw and Borzucki, 1982).

The presence of SMCO and the development of a related anaemia have been linked with poor growth rates and inappetance for some time. Penny et al (1964) reported that, even if animals did not develop severe anaemia, low grade anaemia developed, which they thought could be associated with sub-clinical symptoms of lower liveweight gains and lower productivity. Barry et al (1982) found that intakes of lucerne were depressed when supplemented with synthetic SMCO at 0.6 g SMCO kg W^{-1} and Barry et al (1984b) reported an increase in liveweight gain and wool growth when lambs were grazed on kale containing low (3.5 g SMCO kg^{-1} DM) compared to normal (6.0 g SMCO kg^{-1} DM) SMCO levels. However, Barry et al (1982) observed a greater decrease in voluntary intakes with the kale than with the lucerne diet at similar SMCO intakes. A more severe anaemia in the lambs offered the kale diet than in those offered the lucerne diet was also evident. They attributed these observations to differences in the basal diet; there being a greater ratio of soluble to structural carbohydrates in kale than

in lucerne. This, Barry et al (1982) suggested, would result in a microbial population developing in the rumen of kale-fed sheep which would metabolise SMCO to dimethyl disulphide at a faster rate than that which occurred in the rumen of lucerne-fed sheep. However, no increase in plasma SMCO concentrations were found as dietary SMCO increased in the lucerne diet suggesting that there was no difference between the diets in the conversion of SMCO to dimethyl disulphide. Other experiments (e.g. Smith, 1978; Barry, 1978) have also found differences in the severity of the anaemia observed when different brassica diets of similar SMCO content were offered to lambs, suggesting that there may be other compounds responsible for the development of anaemia which have, as yet to be elucidated.

The importance of the role of SMCO in depressing lamb growth rates and causing inappetance has yet to be completely clarified. For example, Fitzgerald (1985) argued that SMCO was not the major factor in reducing the liveweight gain of lambs grazing rape as there was no improvement in lamb performance when lambs grazing rape offered pasture or hay supplements, thereby reducing the SMCO content of the diet. Also, Young et al (1982) concluded that SMCO intake and subsequent anaemia were not necessarily the most important factor limiting lamb performance on hybrid turnip, since SMCO intakes were at a level (15.7 g SMCO 100 kg W^{-1}) quoted by Smith (1978) as resulting in acute haemolytic anaemia (15 to 20 g SMCO 100 kg W^{-1}) and no anaemia was observed. On the other hand, SMCO has been linked to poor performance in lambs by Barry and co-workers in New Zealand in a number of experiments (Barry et al, 1981a; Barry et al, 1982; Barry et al, 1984b) where SMCO levels have been manipulated. For example, Barry et al (1984b) found that liveweight gains were greater during the

first six weeks after introduction to the crop for lambs grazing kale containing low concentrations of SMCO compared to lambs grazing kale containing normal concentrations of SMCO. The lambs grazing low SMCO kale also showed less severe anaemia and lower blood concentrations of dimethyl disulphide and Heinz bodies.

Smith (1974) suggested that the most likely role for SMCO in the plant was as a pool for organic sulphur. McDonald et al (1981) provided evidence for this by showing that SMCO synthesis in kale is depressed when soil sulphate declines below 9-10 mg kg^{-1} soil, particularly if N is applied at the same time. Growing forage brassica crops on lower-S soils is one means of reducing SMCO content in kale, without depressing DM or N yield. Cultivar (Bradshaw and Borzucki, 1982), harvest date (Bradshaw and Borzucki, 1983) and plant component consumed (Whittle et al, 1976; Sheldrick and Lavender, 1981) have been been found to influence SMCO consumption, and together with the strategic use of the crop, such as with the provision of a run-back area (Smith, 1980), SMCO content in the diet can be reduced, if this is deemed to be necessary. Moreover, Smith (1974) pointed out that there are only a few bacteria which can ferment SMCO to dimethyl disulphide. He suggested that, by inactivating these bacteria, ingestion of SMCO would be harmless. Supplementation with copper too has also been reported to reduce haemolytic anaemia in cattle and result in increased liveweight gains (Barry et al, 1981b).

In summary, SMCO, or more correctly its hydrolysis product, dimethyl disulphide, has been shown to cause haemolytic anaemia in ruminants given forage brassica diets. The extent of the anaemia and its subsequent effect on liveweight gain has also been shown to be partly associated with the level of SMCO intake and also to some other factors

which have yet to be elucidated. If, however SMCO concentration of the forage brassica is considered to adversely affect lamb performance, several methods have been suggested to reduce the level of SMCO in the diet.

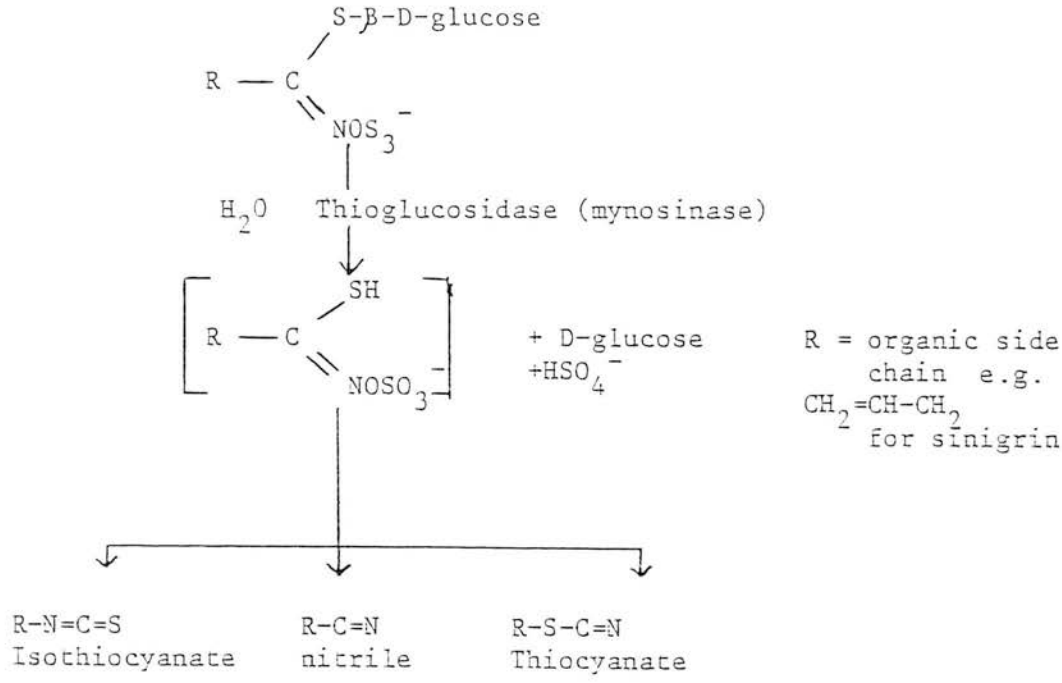
Glucosinolates

There has been little research conducted on the effect of glucosinolates in forage brassicas on ruminant digestion and metabolism, although the effects of glucosinolates in rape seed meal on monogastrics and birds have been extensively studied (see reviews by Van Etten and Tookey (1978) and Thomke (1981). Goitre (enlargement of the thyroid gland) has been reported for a number of years in ruminants grazing brassicas (Chesney et al, 1928; Sinclair and Andrews, 1959; Russel, 1968) but the cause was unknown and it is only relatively recently that glucosinolates have been implicated.

As with SMCO, glucosinolates are only found in a few plant families, i.e. Capparceae, Moringaceae, Resedaceae, Tovariaceae and Crucifereae, of which the brassicas are a part (Kjaer, 1973). Over 90 different glucosinolates have been described (Fenwick et al, 1983), all but one (sinapin) having the same general structure. Individual species contain relatively few glucosinolates and the main glucosinolates present in brassicas have now been described (Van Etten and Tookey, 1979; Bradshaw et al, 1984).

The hydrolysis of glucosinolates has been well documented in a number of reviews (e.g. Tapper and Reay, 1973; Van Etten and Tookey, 1978; Tookey et al, 1980; Fenwick et al, 1983). A summary of the reaction is given in Figure 2.2. Thiocyanate is not normally a hydrolysis product in brassicas (Fenwick et al, 1983) and in glucosinolates possessing a B-hydroxyl group, the isothiocyanate formed is unstable and

FIGURE 2.2. Schematic diagram of glucosinolate hydrolysis (after Tookey et al, 1980)



spontaneously cyclises to form oxozolidine-2-thione (Fenwick and Heaney, 1983). Since little research has been conducted with ruminants, it has to be assumed that similar aglucone products are present in the gut of ruminants as in monogastrics, although Tookey et al (1980) reported some experiments which showed different end products to those occurring in rats.

Thiocyanates and isothiocyanate are considered together, as isothiocyanate can be metabolically converted to thiocyanate (Greer, 1950; Van Etten and Tookey, 1979). In rats, doses of allyl-isothiocyanate inhibit thyroid uptake of radioactive iodine (Langer, 1964) with the thyroid gland showing histological changes indicative of goitre (Langer and Stolc, 1965). These have been confirmed by later workers (Ahmed and Muztar, 1971; Paxman and Hill, 1974). The effects have been shown to be overcome by iodine supplementation (Greer et al, 1966). In ruminants, no direct effects of thiocyanates or isothiocyanates have been reported and all evidence is circumstantial. David (1976) reported that sheep fed kale developed thyroid enlargements and suggested that the major goitrogen in kale was of the thiocyanate type, as the effects were overcome by iodine supplementation. Similar findings were reported by Sinclair and Andrews (1959) and Barry et al (1983a). No increase in lamb liveweight gain was found after iodine supplementation by Sinclair and Andrews (1959), Russel (1967) and Barry et al (1983a). Iodine deficiency, therefore, does not seem to have any marked effect on animal growth. This was confirmed by Potter et al (1980) who offered an iodine-deficient but goitrogenic-free diet to sheep for 20 weeks and found that iodine supplementation did not alter liveweight gains.

The most common compound of the oxaxolidine-2-thiones is 5-vinyl-

oxazolidine-2-thione, commonly known as goitrin. It is thought to be more goitrogenic than isothiocyanate or thiocyanate and its effects on the thyroid are not readily overcome by increasing the iodine content of the diet (Greer et al, 1964). It has shown to act by inhibiting the incorporation of iodine into the precursors of thyroxine and interfering with the secretion of thyroxine (Akibe and Matsumoto, 1976). However oxazolidine-2-thiones are not likely to have a significant effect in animals grazing forage brassicas as the glucosinolates from which they are derived are mainly present in the seeds, not the leaves, stem or bulb of the plant. Elfving (1980) reported that thyroxine synthesis in the rat was inhibited at a daily dose level of 1 ug of oxazolidine-2-thione and goitre was observed at a daily dose level of 5 ug over three weeks. No similar data is available for ruminants but some of the goitrogenic effect observed by David (1976) for sheep offered kale was probably due to oxazolidine-2-thiones as iodine supplementation did not completely overcome the goitrogenic effects.

Nitriles have been considered to be the most toxic of the normal glucosinolate aglucone products (Tookey et al, 1980). The mechanism by which these compounds act is unclear, but Greer (1950) reported that work with rabbits indicated that acetonitrile produced thyroid hyperplasia, which was overcome by iodine administration. However, he could not confirm this in later experiments and it is generally considered that nitriles have no goitrogenic effects (Tookey et al, 1980). Other organs have been shown to be affected by nitriles. Van Etten et al (1969) observed that a crude nitrile fraction from Crambe abyssincica was lethal to rats at a proportion of 0.02 in the ration and with proportions of 0.01 producing liver and kidney lesions. Josefsson (1975) reported that nitriles had a strong growth retarding effect when fed to

mice.

No similar experiments have been reported with ruminants. Forss and Barry (1983) however, incubated kale and swedes in rumen liquor and measured subsequent nitrile production. They concluded, assuming that no rumen degradation of the nitriles produced took place, that nitrile production in ruminants consuming kale would be sufficiently high to cause potential nutritional disorders, based on evidence from monogastrics. No such effects would be expected with swedes as nitrile production in vitro was lower.

The evidence in ruminants of a role for glucosinolate aglucone products in influencing animal performance is as yet inadequate. Glucosinolate aglucone products have, however, been linked with undesirable flavours in meat from animals grazing these crops (Park et al, 1972). Various methods have been suggested to reduce the glucosinolate content of forage brassicas. These have included limiting sulphur availability to the plant (Freeman and Mossadenghi, 1972; Barry et al, 1984b) and breeding low glucosinolate varieties (Johnston and Gosden, 1975; Bradshaw et al, 1984). It has been observed that factors favouring low glucosinolate content are also favourable for low SMCO content (Barry et al, 1984b). However, as the glucosinolates or their aglucone products are thought to have a role as an insect deterrant and are consequently involved in protecting the plant against disease, glucosinolates cannot be totally excluded from the plant.

Unlike SMCO, the role of glucosinolate aglucone products in influencing the nutrition of ruminants has not been elucidated. It is not clear if the pathway of glucosinolate hydrolysis is the same in the rumen as occurs elsewhere. In addition, the effects of these aglucone products are not well understood and have to be assumed to be similar to those

occurring in other animals which is clearly unsatisfactory. However it is interesting to note that conditions which favour lower SMCO concentrations in the plant also favour lower glucosinolate levels and, therefore, if glucosinolate aglucone products are shown to adversely affect animal performance, glucosinolates can be reduced in the plant with the additional benefit of reducing SMCO content.

Supplementation (Section 2.8)

The previous sections have highlighted the generally low intakes and performance by lambs grazing forage brassica crops. While these may be partly explained by the presence of non-protein sulphur compounds, suggestions have been made that intakes and carcase gains may be limited by an imbalance of nutrients, either associated with the ratio of structural:non-structural carbohydrates for rumen function or in terms of absorbed protein:energy ratios.

Ratio of structural:non-structural carbohydrate

Ewer and Sinclair (1952) suggested that rape was "deficient in roughage for good rumen function". However, they reported no benefit to lamb growth when the rape was supplemented with 227 g DM hay day^{-1}. This is in agreement with the later experiments of Fitzgerald (1985) who found that supplementation of rape with either fresh herbage, in the form of a run-back area, or free access to hay had no overall effect on either liveweight gain (49 to 73 g day^{-1}) or carcase gain (50 to 57 g day^{-1}). Ewer and Sinclair (1952) however, did observe an increase in liveweight gain when offering high-quality hay ad libitum (average daily consumption, 250 g DM) to lambs grazing rape but in this case the hay was a major part of the diet.

With root crops, Drew (1968) reported an increase in liveweight gain from 31 to 114 g W day^{-1} when lambs, folded on swedes, were

allowed unlimited access to high quality hay (average daily consumption 300 g DM). Restricting access to the hay to two hours per day (average daily consumption 270 g DM) resulted in lower liveweight gains (76 g W day^{-1}) than unrestricted access. However the unrestricted access, as with the experiment of Ewer and Sinclair (1952), led to the hay being a major part of the diet. Indeed Nicol and Barry (1980) observed that with lambs grazing swedes, the effect of offering supplementary hay was to decrease the metabolic energy intake from swedes by 0.8 KJ ME for each additional 1.0 KJ ME from hay consumed. The only reported experiment where supplementation with a forage increased bulb intake was with ewes in early lactation (Valderrabano et al, 1986), where barley straw supplementation (average daily consumption 320 g DM) resulted in a proportional increase of 0.1 in intake of turnips. This suggests that supplementation with forages may improve the intake of bulb components but the conditions where this may be effective, for example, age of sheep or type of supplement have not yet been elucidated.

Protein/Energy balance

Barry et al (1981a) reported that the empty body weight gains of lambs grazing kale were in the range 76 to 156 g W day^{-1}. Using the derived constants given in ARC (1980) and ARC (1984), it is possible to calculate the intakes of ME and the amounts of NAN at the abomasum that are required to provide these gains, assuming an initial liveweight of 24 kg and that there is only one limiting nutrient. Empty body weight gains of 76 to 156 g day^{-1} require ME intakes of 5.5 to 7.2 MJ ME day^{-1} and NAN flows past the abomasum of 9.9 to 13.4 g day^{-1}.

Dewey and Wainman (1984) found the ME content of Maris Kestrel kale to be 12.6 MJ ME kg^{-1} DM and Barry et al (1984a) reported NAN flows at the duodenum of 16.8 g day^{-1} for kale in relation to a OM

intake of 694 g OM day^{-1}. The NAN flow at the abomasum to ME intake ratio to achieve liveweight gains of 76 to 156 g day^{-1} is 1.8 to 1.9 whilst that derived from experimental observations is 1.2 for kale (Barry et al 1984a). This suggests that NAN flow at the abomasum may limit tissue gain in lambs offered kale and probably other forage brassica diets, although there is no experimental evidence to this effect.

Rather than a general limitation of NAN available for tissue gain, Barry et al (1984a) suggested that there could be a specific amino-acid limitation to tissue gains. As SMCO is structurally similar to methionine, each could act as a competitive inhibitor for the ruminal enzyme systems which degrades the other amino acids in the initial period after introduction to the crop. Both intraperitonal and oral supplements of DL-methionine to lambs grazing kale increased liveweight gains. These results were confirmed in a later experiment (Barry and Manley, 1985) where it was found that 0.28 of the oral supplement escaped degradation in the rumen. This implies that tissue gains in lambs offered leafy forage brassicas may be limited by the amount of sulphur amino-acids absorbed rather than through any action on N digestion in the rumen. However supplementation experiments indicating the sigificance of rumen degradable or undegradable nature of protein on tissue gains have not been reported.

Supplementation of both leaf and stem crops with cereals has been more widely reported but has resulted in little apparent increase in tissue gain. Ewer and Sinclair (1952) found no response to supplementing lambs grazing rape with 227 g DM day^{-1} of oats and Fitzgerald (1983) summarised a number of experiments where he had offered a barley supplement to lambs grazing rape. He concluded that the response to supplementing forage crops such as rape with cereal supplements was

variable and at best limited to a lower level of supplement (225 g DM day^{-1}) for up to five weeks after the start of grazing the crop. He attributed this poor response in increasing gains to cereal supplementation to complete substitution of rape DM intake by the DM intake of the supplement although no direct evidence for such an effect is available.

A possible reason for the lack of response to energy supplementation and the potentially high substitution rates is that forage brassicas, particularly swedes, are in effect a "dilute concentrate" (Drew 1968). Barry et al (1971) described the end-products of rumen digestion of forage brassicas as being similar to those of high concentrate rations with VFA molar proportions being similar to those found with rations containing a proportion of cooked flaked maize. Ørskov et al (1969) reported very small and in most instances, non-significant effects on VFA composition of replacing barley with swedes, while the work of Bath and Rook (1965) showed that the VFA concentrations in the rumen of cows given kale were much closer to barley rations than to other forage crops, such as hay or silage.

With lambs offered bulb components, due to the high ME content of swedes (14.0 MJ ME kg^{-1} DM; Dewey and Wainman, 1984) and low N concentrations, tissue gains are unlikely to be limited by ME intake. No experiments have been reported where bulb components have been supplemented with only cereals. Several experiments have shown a positive response to protein supplementation with soya bean meal (e.g. Fitzgerald 1979; Fitzgerald 1981). Barry and Drew (1978) gave lambs grazing swedes and turnips an intraperitoneal injection of DL-methionine and reported higher rates of liveweight gain than for lambs given no supplement in the first three weeks after introduction to the crop. This

suggests that in lambs offered the bulb component of forage brassicas, tissue gains may be limited by the supply of absorbed amino acids.

In summary, there is inconclusive evidence to suggest that protein or energy supplementation of the leaf and stem of forage brassicas would result in tissue gains. There is some evidence to suggest that protein supplementation leading to higher NAN flows at the abomasum may be effective, although it is not clear if this is a result of a general or specific limitation. Supplementation of leaf and stem components with energy substrates appears to be ineffective because of a high substitution rate, whereas with the bulb components, NAN supply at the abomasum appears to limit tissue gains.

Conclusion (Section 2.9)

The review of literature on forage brassica nutrition has highlighted the following deficiencies in our knowledge which requires to be rectified:

1) Accurate measurement of *in vivo* digestibility of many components of forage brassica crops and the quantification of the sites of digestion in order to establish what are the limiting nutrients to carcase gains.

2) Quantification of the voluntary intakes of forage brassica species to confirm that voluntary intakes are lower than would be predicted on the basis of chemical composition. This would enable research on the factors influencing voluntary intakes to be more directional. The role of SMCO in limiting intakes has been demonstrated but little or no information is available on other S-containing compounds, such as glucosinolates and their aglucone products, nor on the other factors which it has been suggested could limit voluntary intake.

3) The effects of amount and type of supplementation on carcase

gains require further investigation particularly in relation to the effect on the intake of forage brassicas by grazing lambs. As there is a paucity of data available on nutrient absorption and utilisation and on substitution rates with forage brassicas, effective supplementation strategies cannot yet be determined.

CHAPTER 3 - EXPERIMENT 1

THE VOLUNTARY INTAKE, APPARENT DIGESTIBILITY AND NUTRIENT FLOW AT THE ABOMASUM OF A RANGE OF FORAGE BRASSICA CROPS OFFERED TO SCOTTISH BLACKFACE LAMBS

INTRODUCTION (Section 3.1)

Chapter 2 demonstrated that for forage brassica crops widely used in lamb finishing systems, there is limited data available on the nutritive value of these crops when offered to lambs. Whilst there is some data on the voluntary intake and apparent digestibility of most crops, and on the ME content of a few, N digestion of these crops by lambs has not been studied. A knowledge of the amount of the nutrients absorbed by lambs ingesting forage brassicas is required in order to obtain an understanding of the nutritional factors limiting lamb performance.

The development of a new system of predicting the N requirements of ruminants (ARC 1980) highlights the lack of data that exists on N digestion of forage brassicas. The new system requires the prediction of the quantity of NAN available for absorption in the small intestine. Apart from the investigation on kale conducted by Barry et al (1984a) no such information is available to test the adequacy of the proposed system.

The objective of this experiment was to describe the amounts of nutrients absorbed by lambs ingesting a range of forage brassicas to allow identification of the nutritional limitations to lamb growth. A sequence of crops was chosen to correspond to the stage of growth and time of year when they are utilised in current agricultural systems. Hybrid turnip and cabbage produce a large quantity of leaf material by early autumn. These crops are followed by stubble turnip as this is usually grazed before rape and kale. Stubble turnip was offered to the lambs as either leaf or bulb, since lambs consume the aerial parts of the

plant before the bulb. Rape and kale were offered as leaf and stem, since the lambs consume the lamina and petiole before ingesting the stem. Only the bulb of swede was offered as by mid winter, when swedes are utilised, the aerial parts have senesced.

MATERIAL AND METHODS (Section 3.2)

The study was conducted over five periods, each of three weeks duration, between late September, 1983 and late January, 1984. In each period, each of two crops or crop components were offered to six Scottish Blackface wether lambs. The sequence of crops was as follows:

Period	Treatment code	Crop Description
1	A	Hybrid turnip (cv. Tyfon)
	B	Cabbage head (cv. Stonehead F1)
2	C	Stubble turnip leaf (cv.Civesto)
	D	Stubble turnip bulb
3	E	Rape leaf (cv. Lair)
	F	Rape stem
4	G	Kale leaf (cv.Maris Kestrel)
	H	Kale stem
5	I	Swede bulb (cv. Ruta Otofte)

Animals

Seventeen Scottish Blackface wether lambs, aged five months and weighing 30.5 (s.e. = 0.44) kg at the beginning of period 1, were obtained from Hill Farming Research Organisation's Sourhope Research Station, Yetholm, Roxburgh in early August. In late August, they were prepared with a rumen cannulae (4 cm diameter) and a simple T-shaped cannulae inserted into the abomasum (Kay and McKenzie, 1968; Hecker, 1974).

The lambs were offered dried grass pellets ad libitum until the experimental forage brassica diets were offered in mid-September. They were housed at the Hill Farming Research Organisation's Hartwood Research Station, Shotts, Strathclyde, for the first four periods of the

experiment, and at Bush Estate, Penicuik, Midlothian, for period 5. The lambs were dosed with 1 g of copper needles in July at the end of August they received a clostridium/pneumonia vaccination (Heptavac-P, Hoescht). This was repeated six weeks later at the end of period 1.

The twelve lambs with the highest voluntary intakes of forage brassica were randomly allocated a number, which determined their sequence of treatments as outlined in Table 3.1.

TABLE 3.1 Sequence of crop treatments for Experiment 1

Lamb No.	1	2	3	4	5	6	7	8	9	10	11	12
Period 1	A	A	A	A	A	A	B	B	B	B	B	B
2	C	C*	C	D	D*	D	C	C	C	D	D	D
3	E*	F	F	E	E	F	E*	E	F	E	F	F
4	G*	G	H	G	H	H*	G	H	H	H	G	G
5	I	I	I	I	I*	I*	I	I	I	I	I*	I*

The sequence was designed to be a form of controlled randomisation. The five remaining lambs were used as substitutes during the study, replacing animals whose intakes was less than 50% of the mean of the group. Once included, the substitute followed the sequence of the lamb that it replaced for the remainder of the study. The substitute animals were offered forage brassica crops throughout the study and the replaced animals, when they regained their former intake level, were part of this group. The substitutions are marked (*) in Table 3.1.

Feeds

An area (0.25 ha) was sown with hybrid turnip, stubble turnip, rape and kale on June 25, 1983 at Hartwood Research Station, Shotts, at a seed rate of 7.00 kg ha^{-1} with 625 kg ha^{-1} of a 22:11:11 compound fertiliser being applied to the seed bed. These crops were harvested daily. Cabbage and swede crops were grown at Roslin, Midlothian. The

cabbages were harvested weekly and stored in a cool area. The swedes were harvested in December and stored in a cool and frost-free area until required in January.

The hybrid turnip crop was cut at ground level using a reciprocating blade mower (Agria, West Germany). The stubble turnip, crop was harvested monthly. The bulb was washed and the leaf and bulb separated by hand. The rape and kale crops were harvested using a rotary cutter (Fuji, Japan). The leaf portion was harvested as all the plant material above and including the first node of each plant. This was gathered and then the stem portion was cut to ground level and gathered. The proportion of lamina, petiole and stem components of rape and kale are given in Table 3.2. There were traces of weed species.

TABLE 3.2 Proportion of lamina, petiole, stem components in rape and kale crops

		lamina	petiole	stem
rape	leaf	0.52	0.33	0.14
	Stem	0.0	0.02	0.98
kale	leaf	0.46	0.27	0.26
	stem	0.0	0.02	0.98

Prior to feeding, all crop or crop components were chopped into approximately 4 cm lengths using a root chopper for the bulb components and a chaff cutter for the other components. A sample of each crop component was taken daily and a representative sub-sample taken for a DM determination (oven dried at 80°C for 24 h). The remainder of the sample was bulked over each sub-period. A sub-sample was frozen at -20°C, freeze-dried, ground and then analysed for OM, N, NDF, ADF and ADL concentrations. SMCO, total glucosinolate and individual glucosinolate concentrations were determined on freeze-dried, ground material, kept stored at -20°C.

Measurements

Sub-period 1. After being offered the diet ad libitum for seven days, the lambs were transferred from individual pens to metabolism cages. Voluntary intake and faeces and urine outputs were measured over the subsequent seven days using conventional procedures.

The diet was offered twice daily at 0900h and 1630h with a refusal margin of 0.20. Refusals and faeces were collected daily at 0800h, weighed and sub-sampled for DM determination with the remainder of the sample being retained frozen for freeze-drying, grinding and analysis for OM, N, and NDF concentrations.

Urine output was measured daily. A representative aliquot (0.01) of urine was taken each day, bulked and frozen at -20°C until subsequently analysed for N concentration. The urine was collected into 20 mls of 1.9M sulphuric acid.

Sub-period 2. Digesta flow rates at the abomasum were measured in sub-period 2. The amount of feed offered was reduced to 0.85 of the voluntary intake of sub-period 1 to minimise refusals. The diet was offered in equal amounts, four times daily at 0900h, 1300h, 1630h and 2200h. Five days prior to the first two sampling days, the particulate and liquid phase markers, ^{103}Ruthenium phenanthroline and ^{51}Chromium-EDTA, prepared by the method of Tan, Weston and Hogan (1971), were continuously infused intraruminally at the rate of 10 µCi ^{103}Ru and 50 µCi ^{51}Cr per day. Thirty-six hours prior to the first sampling day, sodium ^{35}sulphate was continously infused intraruminally at the rate of 80 µCi ^{35}S per day to measure microbial protein production rate in the rumen (Mathers and Miller, 1980).

The two sampling days were separated by a 24h period. On each of the sampling days, approximately 100 mls of abomasal contents were

withdrawn from the abomasal cannulae of the lambs at 1000h, 1400h, 1800h, 2000h, 0100h and 0700h. The samples were stored at 4°C and bulked for each lamb at the end of the 24h period. Figure 3.1 gives details of the method used to obtain samples of whole, precipitate and microbial fractions of abomasal contents.

At the same sampling times approximtely 20 mls of liquor was withdrawn from several areas of the rumen of the lambs using a rumen sampler based on a design developed in the department of Biochemistry and Nutrition, University of New England, Australia. The samples were acidified with two drops of concentrated hydrochloric acid, bulked over the 24 h period for each sheep, and frozen at -20°C until analysed for ammonia and VFA concentrations.

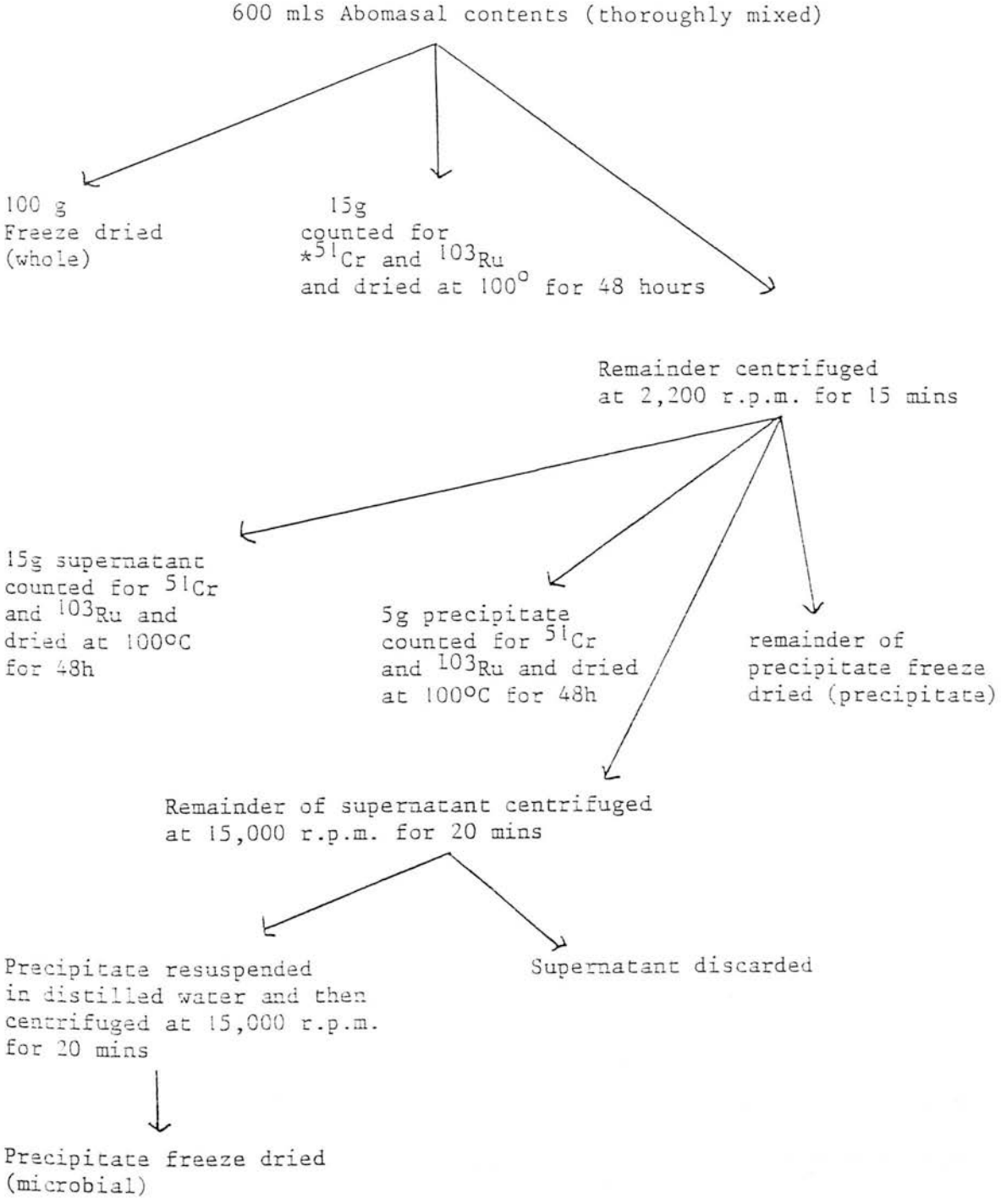
After the last samples had been taken on the second sampling day, the marker infusions were stopped at 0800h and the time recorded. Approximately 15 ml samples of rumen liquor were withdrawn, as described previously, at approximately 0800h, 0900h, 1000h, 1200h, 1500h, 1800h, 2100h and 0800h, the exact time being recorded. These samples were frozen at -20°C and subsequently counted for ^{51}Cr, using the window setting previously described, to estimate rumen liquid volume and liquid outflow rate (Faichney, 1975). Between the two sampling days, approximately 10 mls of blood were withdrawn by jugular venopuncture from each lamb and analysed for serum copper concentration.

Chemical Analyses

Ash content was determined by ashing samples in a furnace for 16 h at 450°C. NDF was estimated using the method described by Van Soest and Wine (1967). ADF and ADL were determined using the method of Van Soest (1963).

Total N was estimated by a semi-micro kjeldahl block digestion

FIGURE 3.1 Processing of Abomasal Digesta Samples



*^{51}Cr and ^{103}Ru counts were obtained using an Auto Gamma 800, Packard, Illinois with the windows being set between 240 and 400 KeV for ^{51}Cr and 400 to 700 KeV for ^{103}Ru.

method, using the Berthelot reaction (Berthelot, 1859), with a continuous flow auto-analyser system. Ammonia N was determined using the method described by Manston (1970). VFA concentrations were determined using the method of Ziolecki and Kwiathowska (1973) with the samples being prepared as described by Erwin et al (1961).

Microbial protein production was estimated using a modification of the technique described by Mathers and Miller (1980). The modifications were that the freeze-dried samples did not undergo oxidation with performic acid prior to acid hydrolysis. After acid hydrolysis, the samples were reduced to near dryness by a continous stream of air being directed onto the surface of the liquid. One ml each of saturated Barium Chloride and 0.1 M Barium Sulphate were added to the test tube, the contents mixed thoroughly and then centrifuged at 2,500 r.p.m. for 10 minutes.

Serum copper concentrations were estimated by pulse nebulisation using an Atomic Absorption Spectrometer (I.L. 251, Instrumentation Laboratories) with wavelength set at 324.7 nm and the samples being measured against known standards.

SMCO concentration was measured using the method described by Gosden (1979). Total glucosinolate concentration, as estimated by thiocyanate ion concentration, was measured using the method described by Gosden (1978). Individual glucosinolate concentrations were estimated using the procedures described by Heaney and Fenwick (1980).

RESULTS (Section 3.3)

Sub-Period 1. The chemical composition of the crop components offered in sub-period 1 is given in Table 3.3. All crop components were characterised by having a low DM content and with the exception of rape stem low NDF, ADF and ADL contents. The bulb components had

lower N, NDF, ADF and ADL contents than those of the leaf components. Kale stem had a similar composition to leaf components but rape stem had higher NDF, ADF and ADL contents than the other crop components.

SMCO content ranged from 25 g SMCO kg^{-1}DM (hybrid turnip leaf) to 110 g SMCO kg^{-1}DM (kale leaf) and total glucosinolate content ranged from 1.09 mmole kg^{-1}DM (swede bulb) to 19.32 mmole kg^{-1}DM (rape leaf). The individual glucosinolate concentration are given in Table 3.4, and show that only a few glucosinolates are present in each crop.

The voluntary intakes and apparent digestibilities of DM and OM of the crop components are given in Tables 3.5 and 3.6. All means are of six observations except those of stubble turnip bulb (five) and swede bulb (seven). Voluntary intakes of OM ranged from 17 to 24 g OM $kg^{-1}W$ day^{-1}. Apart from the lower values for rape stem (0.773), the leaf and stem components had similar apparent digestibilities of OM (0.881 to 0.911). The bulb components had higher values for the apparent digestibility of OM than those of the leaf components. The values for the apparent digestibility of NDF are also given in Table 3.6 and were in the range 0.636 to 0.859 with those of the stem components being lowest.

The intakes and apparent digestibility values of N and losses in the faeces and urine of N are given in Table 3.7. The intakes of N by lambs offered the leaf components or kale stem were 60% higher than those offered the bulb components or rape stem, reflecting the different N concentrations of the components. Apparent digestibility values of N ranged from 0.769 to 0.868. Losses of N in the faeces were considerably lower than losses of N in the urine, reflecting the high apparent digestibility of N. Lambs offered the bulb components had

TABLE 3.3. Chemical description of crop components offered in Sub-period 1.

	DM (gkg^{-1})	Ash (gkg^{-1}DM)	N (gkg^{-1}DM)	NDF (gkg^{-1}DM)	ADF (gkg^{-1}DM)	ADL (gkg^{-1}DM)	SMCO (gkg^{-1}DM)
Cabbage	64	146	30.8	228	220	5.4	7.2
Hybrid turnip leaf	75	143	28.7	201	194	11.4	2.5
Stubble turnip leaf	98	176	26.6	231	229	11.7	3.3
Rape leaf	124	115	32.3	206	186	12.0	8.8
Kale leaf	131	119	34.6	183	164	14.5	11.0
Rape stem	154	78	19.8	398	322	44.8	7.0
Kale stem	130	105	27.1	198	170	12.9	8.3
Stubble turnip bulb	81	115	17.6	173	159	8.2	4.8
Swede bulb	117	115	18.8	163	155	6.8	6.3

TABLE 3.4. Content of individual glucosinolates of crop components offered in Sub-period 1

	*methylsulphinyl and/or methyl/sulphonyl	2-hydroxy-3 butenyl	allyl	2-OH-pent 4-enyl	But-3-enyl	Pent-4-enyl	3-indole-methyl	4-methoxy-3 indole methyl and/or phenylethyl	1-methoxy-3-indole methyl
Cabbage	2.44	-	4.23	-	-	-	0.42	0.13	-
Hybrid turnip leaf	-	1.80	-	3.24	0.31	2.59	0.50	0.82	2.15
Stubble turnip leaf	-	5.82	-	2.63	0.83	1.62	0.24	0.48	0.34
Rape leaf	-	7.48	-	3.07	1.69	5.50	0.62	0.64	0.32
Kale leaf	0.68	-	2.32	-	-	-	2.15	0.19	0.19
Rape leaf	-	5.18	-	2.81	0.43	1.59	0.29	0.96	0.18
Kale stem	trace	-	1.37	-	-	-	0.29	0.25	0.13
Stubble turnip bulb	-	3.46	-	1.50	-	0.45	0.21	1.31	0.36
Swede bulb	-	0.72	0.26	-	-	-	0.11	-	-

*side-chains of glucosinolates

TABLE 3.5. Voluntary intake and apparent digestibility of DM of crop components by lambs in Sub-period 1.

	Voluntary intake ($gDMday^{-1}$)	s.e.	Voluntary intake ($gDMkg^{-1}Wday^{-1}$)	s.e.	Apparent digestibility	s.e.
Cabbage	590	45.9	19.5	1.51	0.846	0.0082
Hybrid turnip	804	37.2	26.0	0.88	0.831	0.0085
Stubble turnip leaf	776	73.6	25.8	1.89	0.818	0.0070
Rape leaf	740	65.1	24.1	1.72	0.849	0.0070
Kale leaf	623	58.1	19.4	1.56	0.852	0.0116
Rape stem	631	44.0	19.5	0.85	0.763	0.0082
Kale stem	669	104.2	20.5	2.33	0.862	0.0025
Stubble turnip bulb	794	69.4	27.3	2.03	0.889	0.0062
Swede bulb	746	69.4	21.0	1.51	0.905	0.0074

Table 3.6. Voluntary intake of OM and apparent digestibility of OM and NDF of crop components by lambs in Sub-period 1

	Voluntary intake ($g\ day^{-1}$)	s.e.	Voluntary intake ($g\ kg^{-1}W\ day^{-1}$)	s.e.	Apparent digestibility of OM	s.e.	Apparent digestibility of NDF	s.e.
Cabbage	515	39.7	17.0	1.30	0.911	0.0045	0.859	0.0067
Hybrid turnip leaf	691	32.2	22.4	0.77	0.881	0.0077	0.844	0.0227
Stubble turnip leaf	644	62.6	21.4	1.63	0.877	0.0053	0.814	0.0227
Rape leaf	654	58.6	21.3	1.55	0.881	0.0062	0.811	0.0082
Kale leaf	551	50.9	17.2	1.36	0.893	0.0087	0.796	0.0111
Rape stem	584	40.0	18.1	0.80	0.773	0.0092	0.584	0.0215
Kale stem	606	95.7	18.5	2.17	0.886	0.0026	0.636	0.0350
Stubble turnip leaf	698	69.0	24.0	2.02	0.927	0.0024	0.763	0.0322
Swede bulb	672	61.8	18.9	1.34	0.943	0.0044	0.791	0.0267

TABLE 3.7. Intake and apparent digestibility of N and losses of N in faeces and urine by lambs offered crop components in Sub-period 1.

	Intake of N ($g day^{-1}$)	s.e.	Intake of N ($g kg^{-1} W^{0.75} day^{-1}$)	s.e.	Apparent Digestibility of N	s.e.	Loss of N in faeces ($g\ day^{-1}$)	s.e.	Loss of N in urine ($g day^{-1}$)	s.e.
Cabbage	18.2	1.21	1.41	0.098	0.851	0.0098	2.69	0.205	17.9	1.20
Hybrid turnip	23.8	0.84	1.82	0.052	0.825	0.0114	4.19	0.377	16.1	0.39
Stubble turnip leaf	20.7	1.74	1.62	0.119	0.793	0.0114	4.34	0.527	18.2	1.03
Rape leaf	24.3	1.96	1.86	0.137	0.847	0.0099	3.71	0.363	23.5	1.43
Kale leaf	21.5	1.89	1.60	0.134	0.868	0.0100	2.86	0.307	17.3	1.30
Rape stem	12.3	0.93	0.91	0.051	0.769	0.0120	2.83	0.136	12.5	1.06
Kale stem	17.7	2.60	1.29	0.162	0.858	0.0040	2.52	0.389	16.1	1.91
Stubble turnip bulb	13.5	1.02	1.07	0.078	0.777	0.0157	3.05	0.389	10.9	0.70
Swede bulb	14.0	1.17	0.96	0.071	0.826	0.0153	3.05	0.569	11.2	0.84

lower losses of N in urine than those offered either the stem or leaf components.

Sub-Period 2. The chemical composition of the crop components offered during sub-period 2 is given in Table 3.8. Apart from some small differences in N and NDF concentration, they are similar to those presented in Table 3.3 for sub-period 1.

Since there was no significant difference between the DM and OM flow rates at the abomasum between days 1 and 2, the data presented are the combined data for both days. Data for days 1 and 2 are given in Appendix Table 3.2. Table 3.9 and 3.10 give the intakes and flow rates of DM and OM at the abomasum during sub-period 2. OM intakes and flows at the abomasum were in the range 390 to 641 and 129 to 226 g OM day^{-1} respectively. The proportions of OM intake and DOM intake apparently digested in the rumen are also given in Table 3.10. The latter were derived from values for the digestibility of OM obtained in sub-period 1. Proportions of OM and DOM intake apparently digested in the rumen were in the range 0.54 to 0.73 and 0.67 to 0.79 respectively.

The intakes of NDF and the flows of NDF and ADF at the abomasum are given in Table 3.11. The limited number of observations arose because of shortage of sample. NDF flows at the abomasum were in the range 25 to 106 g NDF day^{-1} with values for the ADF flows being similar but slightly lower than those for the NDF flows at the abomasum. The proportions of NDF intake and digestible NDF intake, again using the apparent digestibility of NDF values obtained in sub-period 1, apparently digested in the rumen are also given in Table 3.11. The proportions apparently digested in the rumen were in the range 0.24 to 0.64 and 0.12 to 0.54 for NDF intake and digestible NDF intake respectively.

TABLE 3.8. Chemical description of crop components offered in Sub-period 2

	DM (g kg^{-1})	Ash (g kg^{-1} DM)	N (g kg^{-1} DM)	NDF (g kg^{-1} DM)	ADF (g kg^{-1} DM)	ADL (g kg^{-1} DM)
Cabbage	66	157	26.9	201	184	6.1
Hybrid turnip	77	144	26.0	202	198	11.6
Stubble turnip leaf	98	145	28.2	214	201	11.7
Rape leaf	124	107	32.6	177	166	10.5
Kale leaf	133	126	35.4	163	158	6.7
Rape stem	152	74	19.8	373	303	38.3
Kale stem	132	114	26.8	214	184	15.8
Stubble turnip bulb	81	99	14.6	173	143	6.9
Swede bulb	113	96	19.2	163	148	13.6

TABLE 3.9. Intake and flow at abomasum of DM in lambs given forage brassica crops in Sub-period 2 (combined day 1 and day 2)

	No of observations	Intake of DM ($g\ day^{-1}$)	s.e.	DM flow at abomasum ($g\ day^{-1}$)	s.e.	g DM flow at abomasum per g DM intake	s.e.
Cabbage	6	460	60.8	218	28.6	0.48	0.013
Hybrid turnip leaf	6	667	34.3	345	12.6	0.52	0.020
Stubble turnip leaf	6	624	60.0	336	39.4	0.53	0.030
Rape leaf	4	577	32.6	265	16.0	0.46	0.021
Kale leaf	6	540	42.8	284	31.6	0.52	0.024
Rape stem	5	516	38.0	290	28.6	0.56	0.026
Kale stem	6	574	80.3	273	35.8	0.48	0.018
Stubble turnip bulb	6	710	44.1	261	25.6	0.37	0.027
Swede bulb	7	506	43.7	240	15.8	0.48	0.027

TABLE 3.10. Intake and flow at abomasum of OM and apparent digestion of OM in the rumen of lambs given forage brassica crops in Sub-period 2.

	Intake of OM (g day^{-1})	s.e.	OM flow at abomasum (g day^{-1})	s.e.	Proportion of OM intake apparently digested in rumen	s.e.	Proportion of DOM intake apparently digested in rumen	s.e.
Cabbage	390	51.2	129	15.3	0.66	0.011	0.73	0.013
Hybrid turnip leaf	568	28.5	226	10.9	0.60	0.017	0.68	0.020
Stubble turnip leaf	533	51.2	178	23.0	0.67	0.017	0.77	0.021
Rape leaf	516	29.1	180	21.8	0.66	0.029	0.74	0.039
Kale leaf	472	37.5	201	24.4	0.58	0.025	0.67	0.014
Rape stem	474	36.8	218	21.4	0.54	0.013	0.68	0.030
Kale stem	510	71.7	197	30.6	0.61	0.025	0.69	0.029
Stubble turnip bulb	641	39.9	173	21.9	0.73	0.028	0.79	0.030
Swede bulb	465	40.5	159	10.9	0.65	0.015	0.70	0.020

TABLE 3.11. Intake of NDF, flow of NDF and ADF at abomasum and apparent digestion of NDF in the rumen of lambs given forage brassica crops during Sub-period 2.

	No of obser-	Intake of NDF ($gday^{-1}$)	s.e.	NDF flow at abomasum ($gday^{-1}$)	s.e.	Proportion of NDF intake apparently digested in rumen	s.e.	Proportion of digestible NDF apparently digested in rumen	s.e.	ADF flow at abomasum($gday^{-1}$)	s.e.
Cabbage	5	97.5	10.14	77.3	15.02	0.24	0.100	0.12	0.115	63.9	[illegible]
Hybrid turnip leaf	1	135.7	-	60.2	-	0.56	-	0.43	-	51.3	
Stubble turnip leaf	5	128.6	14.55	92.2	18.86	0.40	0.137	0.23	0.200	89.7	[illegible]
Rape leaf	4	100.8	5.65	53.4	15.89	0.44	0.194	0.29	0.253	46.0	[illegible]
Kale leaf	4	84.8	10.71	29.5	2.92	0.64	0.041	0.54	0.050	16.0	[illegible]
Rape stem	3	213.1	13.68	106.2	20.47	0.50	0.079	0.16	0.088	79.6	[illegible]
Kale stem	5	127.8	20.21	57.9	16.26	0.56	0.081	0.28	0.140	45.5	[illegible]
Stubble turnip leaf	5	116.9	6.59	57.5	14.51	0.51	0.126	0.39	0.140	43.6	[illegible]
Swede bulb	5	72.9	7.42	25.2	4.64	0.61	0.097	0.51	0.115	21.7	[illegible]

TABLE 3.12. Intake N and flow of N and NAN at abomasum of lambs offered forage brassica crops in Sub period 2.

	No of observations	Intake of N ($gday^{-1}$)	s.e.	Total N flow at abomasum ($gday^{-1}$)	s.e.	NAN flow at abomasum ($gday^{-1}$)	s.e.	g NAN flow at abomasum per g N intake	s.e.	g NAN flow at abomasum per kg OM apparently digested in rumen	s.e.
Cabbage	6	11.9	1.75	9.8	1.26	9.5	1.24	0.82	0.059	24.4	1.17
Hybrid turnip leaf	6	17.5	0.80	17.5	0.48	16.7	0.46	0.96	0.030	29.7	1.13
Stubble turnip leaf	6	17.7	1.68	13.2	1.84	12.5	1.76	0.70	0.049	23.3	1.55
Rape leaf	4	19.2	1.28	13.1	1.30	12.6	1.29	0.66	0.033	24.3	1.27
Kale leaf	6	19.7	1.73	14.3	1.60	13.6	1.51	0.69	0.024	28.6	1.15
Rape stem	5	10.1	0.76	8.9	1.50	8.3	1.34	0.80	0.076	17.1	1.62
Kale stem	6	15.2	2.12	12.1	1.76	11.6	1.68	0.77	0.062	23.0	1.91
Stubble turnip bulb	6	10.2	0.61	13.9	1.71	13.7	1.72	1.33	0.127	21.3	2.08
Swede bulb	7	9.7	0.84	12.0	1.17	11.7	1.13	1.20	0.066	25.1	1.41

TABLE 3.13. Concentrations of Ammonia and VFAs in the rumen of lambs offered forage brassica crops in Sub-period 2.

	Ammonia (mgl^{-1})	s.e.	Total VFAs ($mmoll^{-1}$)	s.e.	Molar proportions of VFAs: Acetate	s.e.	Propionate	s.e.	Butyrate	s.e.
Cabbage	161.2	8.67	37.3	1.75	0.61	0.012	0.29	0.017	0.10	0.010
Hybrid turnip leaf	117.0	3.86	53.5	2.93	0.61	0.013	0.30	0.016	0.09	0.007
Stubble turnip leaf	168.3	12.50	68.7	1.96	0.61	0.006	0.29	0.009	0.10	0.005
Rape leaf	183.6	10.71	61.6	1.69	0.61	0.010	0.28	0.008	0.11	0.008
Kale leaf	182.8	15.62	62.3	4.25	0.66	0.007	0.22	0.008	0.12	0.005
Rape stem	200.6	21.85	64.3	1.36	0.61	0.010	0.28	0.014	0.11	0.006
Kale stem	194.6	17.61	71.3	2.99	0.64	0.003	0.27	0.008	0.09	0.007
Stubble turnip bulb	56.7	12.64	56.0	3.08	0.47	0.010	0.41	0.012	0.12	0.011
Swede bulb	75.7	4.02	46.2	2.02	0.56	0.012	0.33	0.018	0.11	0.011

TABLE 3.14. The flow of microbial N at the abomasum and the proportion of NAN that was of microbial in origin in Sub-period 2.

	No of Observations	Flow of microbial N at abomasum ($gday^{-1}$)	s.e.	Proportion of NAN flow of microbial origin	s.e.	g Microbial N flow at abomasum per kg OM apparently digested in rumen	s.e.
Cabbage	1	11.7	-	0.928	-	46.0	-
Hybrid turnip leaf	4	15.4	0.75	0.913	0.0299	49.4	5.33
Stubble turnip leaf	2	11.9	3.59	0.798	0.0079	31.5	5.20
Rape leaf	2	9.5	0.44	0.841	0.0697	30.9	0.25
Kale leaf	0	-	-	-	-	-	-
Rape stem	3	5.8	0.54	0.826	0.0576	25.3	3.75
Kale stem	3	12.1	2.58	0.900	0.0174	30.7	0.79
Stubble turnip leaf	2	8.5	0.86	0.892	0.0104	21.1	4.90
Swede bulb	3	8.7	0.65	0.858	0.0421	31.2	3.97

The intakes of N and flows of total N and NAN at the abomasum are given in Table 3.12. The wide range of intake of N (10.0 to 20.5 g N day^{-1}) reflects the variation in DM intake and also the concentration of N in the DM. The NAN flows (g per g N intake) of the leaf and stem components were in the range 0.70 to 0.82, with the exception of a higher value of 0.92 for the hybrid turnip leaf diet. The bulb components had higher values (1.23 and 1.33 respectively). Apart from the higher values for kale and hybrid turnip leaf (0.050 and 0.051), the values for the amount of NAN flowing at the abomasum relative to the amount of OM apparently digested in the rumen were in the range of 0.030 to 0.040 g NAN g OM^{-1} digested in the rumen.

Rumen ammonia concentrations (Table 3.13) showed a similar pattern to the NAN flows at the abomasum with the rumen ammonia concentrations of the leaf and stem components being higher (161 to 201 mgl^{-1}) than those of the bulb components (56 to 76 mgl^{-1}). Total VFA concentrations (Table 3.13) were in the range 37 to 69mmoll^{-1} for the leaf components, 64 to 71mmoll^{-1} for the stem components and 56 to 63mmoll^{-1} for the bulb components. The molar proportions of acetate, propionate and butyrate are also given in Table 3.13. The leaf and stem components had similar molar proportions of acetate: propionate: butyrate (61 : 29 : 10). The bulb components had a higher proportion of propionate to acetate than the leaf and stem components.

The estimated flow rate of microbial N at the abomasum and the proportion of NAN considered to be microbial in origin are given in Table 3.14. The proportion of the NAN flow at the abomasum that was of microbial origin ranged from 0.798 to 0.928. It was observed that in the majority of cases, the number of counts of ^{35}S in the microbial fraction were less than in the whole or precipitate fractions and this is

TABLE 3.15. Distribution of counts of ^{35}S between whole, precipitate and microbial fractions of abomasal digesta of lambs given forage brassica crops in Sub-period 2.

	No of Observations	Proportion of observations where microbial fraction smaller than either whole or precipitate fractions.	Proportion of observations where microbial fraction less than 0 to 50% higher than whole and precipitate fractions.
Cabbage	11	0.91	0.91
Hybrid turnip leaf	11	0.64	0.64
Stubble turnip leaf	11	0.54	0.82
Rape leaf	8	0.38	0.75
Kale leaf	11	0.91	1.00
Rape stem	9	0.56	0.67
Kale stem	12	0.42	0.75
Stubble turnip bulb	9	0.67	0.78
Swede bulb	13	0.69	0.77

TABLE 3.16. Daily fractional outflow rates of liquid from the rumen and rumen volumes of lambs given forage brassica crops in Sub-period 2.

	Liquid outflow for rumen ($l\ day^{-1}$)	s.e.	Daily Fractional outflow rate of liquid	s.e.	Rumen volume (l)	s.e.	Rumen volume per kg OM intake ($lKg^{-1}OMI$)	s.e.
Cabbage	6.0	0.38	1.20	0.166	4.6	0.36	11.62	2.242
Hybrid turnip leaf	9.6	0.56	1.78	0.149	5.5	0.45	9.96	1.323
Stubble turnip leaf	9.7	1.11	1.71	0.118	5.7	0.62	10.54	0.857
Rape leaf	8.0	0.62	2.11	0.042	3.8	0.26	6.89	0.428
Kale leaf	7.6	1.62	1.79	0.146	4.3	0.87	9.22	1.418
Rape stem	6.7	0.50	1.23	0.068	5.6	0.69	11.52	0.825
Kale stem	5.3	0.34	1.74	0.217	3.3	0.34	7.09	1.121
Stubble turnip bulb	8.2	0.84	1.48	0.144	5.7	0.55	9.23	0.955
Swede bulb	6.8	0.65	1.16	0.063	6.3	0.55	12.11	1.071

demonstrated in Table 3.15. Using the same technique at the Hill Farming Research Organisation, with sheep given grass diets, it was observed that the number of counts in the microbial fraction was always between 0 and 50% greater than on the whole and precipitate fraction. (Milne, J.A. pers. comm.). In the current experiment, between 0 and 36% of the observations for each crop or crop component lay within this range (Table 3.15) and these observations make up the means in Table 3.14.

Fractional outflow rates of liquid from the rumen and rumen volumes during sub-period 2 are given in Table 3.16. There was considerable variation in both fractional outflow rate and rumen volume. Daily fractional outflow rate ranged from 1.16 to 2.11 and rumen volume from 6.9 to 12.1 l kg^{-1} OM intake.

Plasma copper levels were in the range 60 to 100 ug $100ml^{-1}$ which is within the normal range for lambs of this age. The data for individual animals used to derive all the means in this experiment is given in Appendix Tables 3.1 and 3.2.

DISCUSSION (Section 3.4)

The principal aim of this experiment was to describe the nutritive value of a range of forage brassicas, offered to Scottish Blackface wether lambs, at a time of year and stage of maturity when the crops would be grazed in current management systems. It was not intended to make comparisons between crops or crop components as crop and time were confounded.

Apparent Digestibility

The apparent digestibilities of OM found in this experiment were similar to those observed in other studies. For example, Barry et al (1984) obtained values for kale leaf and stem of 0.883 and 0.877 (s.e.,

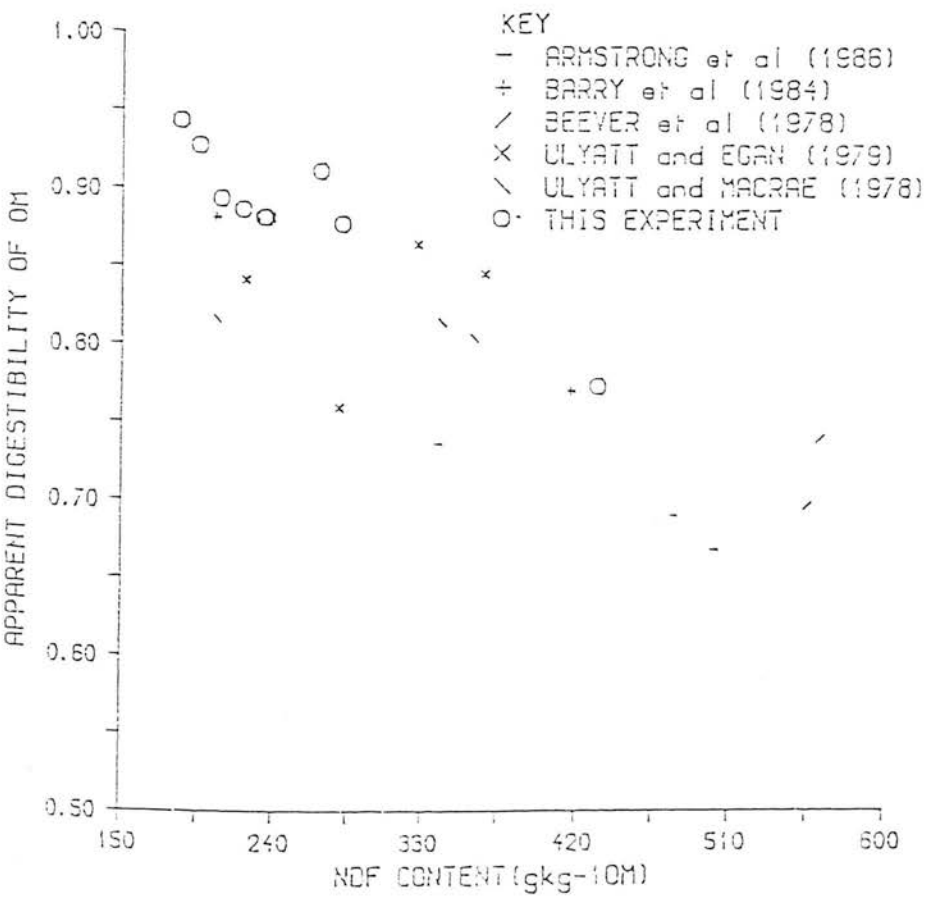
0.0074) respectively compared to values of 0.893 and 0.886 found in this study. For bulb components, Barry et al (1971) found the digestibility of OM for swede bulb to be 0.921, which is similar to the value of 0.943 found in this study.

The values for the apparent digestibility of OM are higher than those normally found in non-brassica herbage diets. However when NDF content was related to apparent digestibility of OM of fresh brassicas and non-brassica forages offered to sheep using data from the literature (see Figure 3.2), both forage brassica and non-forage brassica forages fitted the same general negative linear relationship. The high apparent digestibility of forage brassica diets would therefore appear to reflect their low structural carbohydrate content.

Voluntary Intake

Voluntary intakes of OM were in the range 17 to 24 g OM kg^{-1} W day^{-1}. There have been few measurements of voluntary intake by lambs reported for forage-brassica crops with which to compare the present data. Armstrong (1984) observed voluntary intakes of OM of 18.4 and 16.4 g OM kg^{-1} W day^{-1} for rape leaf and stem respectively. Pelletier and Donefer (1973) reported a value of 60.4 g DM kg^{-1} $W^{0.75}$ day^{-1} for kale leaf which was similar to the values reported in this study, although Barry et al (1982) observed a value of 38.4 g DM kg^{-1} w day^{-1}. Other, less strictly comparable data quoted in Chapter 2 are in general agreement with the values obtained in this study. Thus, apart from the data of Barry et al (1982), voluntary intakes of forage brassicas found in this study and reported by other workers are lower than the 30 g kg^{-1} W day^{-1} found for comparable lambs ingesting forage diets of high digestibility (for example, Egan and Doyle, 1982; Gibb and Treacher, 1984).

FIGURE 5.2. The relationship between apparent digestibility of OM and NDF content in brassica and non brassica forages



A number of animal and plant factors may have contributed to the low voluntary intakes observed in this study. Possible animal factors include the effects of season and, in particular daylength, the age of the animal and the effects of surgical preparation. Forbes et al (1979) found that lambs of similar age to those used in this study and subjected continuously to long daylengths (16 h) consumed 0.10 more concentrate feed than lambs subjected to short daylengths (8 h). Blaxter et al (1982) again using lambs of similar age, observed that the voluntary intakes of a complete diet was 0.16 greater in early autumn (September and October) that in mid winter (December). Further evidence that decreasing daylength could have an effect in depressing intake is provided in an experiment where lambs of similar age and obtained from the same flock as in this study declined in voluntary intake by 0.21 between September and January (Doney, J.M. pers. comm.). However the decline was only observed to occur in December, by which time most of this study had been completed. Furthermore there was no evidence of a decline in the voluntary intake of the lambs over the period of the experiment. It is therefore concluded that daylength is unlikely to have had a major influence on the low voluntary intakes observed.

Low voluntary intakes of forage brassica diets could be a function of the age of the lambs offered these crops, although age will be confounded to some extent with season. However, in the experiment referred to previously using Scottish Blackface lambs of similar age and liveweight to those in this study, voluntary intakes of a complete pelleted diet containing 0.20 barley straw, (apparent digestibility of OM, 0.60) were in the range 29 to 43 g DM kg^{-1} W day^{-1} (Doney, J.M. pers. comm.), i.e. higher than those reported in this study (19.4 to 27.3 g DM

kg^{-1} W day^{-1}). Forbes et al (1979) also reported higher voluntary intakes of a concentrate diet with lambs of similar age. Armstrong (1984) compared the voluntary intakes of five month old lambs and adult wethers offered rape leaf and stem and found that voluntary intakes in adult and lamb wethers were both low and similar (11.4 to 18.8 g OM kg^{-1} W day^{-1}). The conclusion is, therefore, drawn that the age of the lamb does not contribute significantly to the low voluntary intakes observed with forage brassica diets.

The effect of surgical preparation on voluntary intake has been studied in several experiments. MacRae and Wilson (1977), using 18 month old Scottish Blackface wether, found little difference in voluntary intake between intact sheep and sheep prepared with rumen and simple 'T-shaped' duodenal and ileal cannulae. Cruikshank (1986) also found little difference between 3-month old intact lambs and lambs fitted with simple 'T-shaped' abomasal cannulae in their voluntary intake over a twelve week period. Moreover, a comparison of the data reported by Armstrong (1984), using similar aged, intact animals under identical conditions to those imposed on lambs in this experiment, suggests that the voluntary intake of lambs in this experiment were not depressed by the effects of surgical preparation.

There are a number of possible plant factors which could have contributed to the low voluntary intakes. These include low DM content, high non-structural carbohyrate content, low content of structural carbohyrates, and the presence of SMCO and glucosinolates. Bradshaw et al (1982) suggested that inter alia, the low DM content of forage brassicas may limit their voluntary intake. For example, Gibb and Treacher (1984) found that voluntary intake by lambs was positively related to the DM content of perennial ryegrass and white clover

herbage (DM content in the range 132 to 240 g DM kg^{-1}). However no relationship between DM content (range 64 to 154 g DM kg^{-1}) and voluntary intake (range 17.0 to 24.0 g OM kg^{-1} W day^{-1}) was found in this experiment.

Forage brassicas have a high non-structural carbohyrate content and its rapid fermentation in the rumen could lead to a possible involvement of VFAs in intake regulation. Forbes (1986), recently reviewed the evidence for negative feedback pathways involving VFAs in controlling intake. Although the evidence is somewhat conflicting, there are some experiments, such as that of Baile and Mayer (1969), which show clearly a depression in voluntary intake by goats given intraruminal injections of solutions of VFAs during spontaneous meals. VFA production rates in the rumen were not measured in this or any other experiment with forage brassica diets, but from relationships between the amount of OM apparently digested in the rumen and VFA production rates (Sutton, 1971), it was estimated that VFA production rates ranged from 4.7 to 7.6 mol day^{-1} (intake in range 515-698 g OM day^{-1}). These values are mainly higher than those reported by Beever et al (1978) (5.14 and 3.90 mol day^{-1}) when intakes of spring and autumn grass were maintained at 847 and 877 g OM day^{-1} respectively. As VFA production rates are higher for forage brassicas per g intake than non-forage brassica herbage diets, the evidence is consistent with a possible implication of VFA's in the control of voluntary intake and in the low voluntary intakes found in forage brassicas.

Another possible factor influencing voluntary intake, connected with the high content of non-structural carbohyrates in forage brassica crops is pH in the rumen (Forbes, 1986). However in the only experiment with forage brassica crops, in which pH was measured, Bath and Rook (1965)

found that the pH in the rumen of cattle grazing marrowstem kale or perennial ryegrass swards was similar for the brassica (pH, 6.06) and non-brassica herbages (pH, 5.84). It is therefore unlikely that pH in the rumen is an important factor accounting for the low voluntary intake observed with brassica diets.

There was no correlation between voluntary intake and structural carbohydrate content found in this study, although, due to the narrrow range of NDF content, this is perhaps not surprising. However, there was indirect evidence that could implicate the low levels of structural carbohyrates in depressing the voluntary intake of all the forage brassicas studied. A large quantity of foam was present in the rumen of lambs offered all the forage brassica diet in this experiment. It is possible that the low fibre content may have led to insufficient rumination taking place with a consequent trapping of gas and the accumulation of foam. Bloat is known to occur in cattle fed on high concentrate and low roughage rations (see review by Howarth, 1975). Clarke and Reid (1974) in their review of foamy bloat in cattle suggested that decreasing dietary roughage content increased the risk of the occurance of bloat. They could not determine from the available data whether this was attributable to a reduction in saliva production or insufficient roughage being present to stimulate erucation. Cole and Mead (1943) attributed the build up of foam in the rumen of bloated animals to the absence of coarse or sharp material necessary to stimulate the nerve fibres terminating in the ruminal mucosa and this may offer an explanation for the large quantitites of foam present in this study.

The build up of foam in the rumen of bloated animals has also been attributed to substances present in the crop which stabilises the

foam. These have included such compounds as pectins, saponins and proteins (see review by Clark and Reid (1974). Long-chain alkanes have not been implicated in the occurance of bloat, but due to their high concentration in the cuticular wax of forage brassicas, for example rape leaf contains 600 mg kg^{-1}DM, it is possible that they may have some effect in producing a stable foam in lambs offered forage brassica diets.

SMCO has been shown to depress voluntary intake in lambs supplemented with synthetic SMCO. Total concentration in the diet was 22.6 kg^{-1} DM (Barry et al, 1982). However, in this experiment, there was no significant correlation ($r = 0.38$, $P>0.05$) between voluntary intake and SMCO concentration, (range 2.5 to 11.0 g kg^{-1} DM). The SMCO content in forage brassicas in this experiment was considerably lower than in the experiment of Barry et al, (1982) and therefore would be unlikely to be the cause of the low voluntary intakes observed.

No significant correlation ($r^2 = 0.09$, $P>0.05$) was found between voluntary intake and total glucosinolate concentration in the forage brassica diets (range 43 to 142 mg kg^{-1} DM). However, there were some significant ($P < 0.05$) negative relationships between individual glucosinolates, particularly methy sulphinyl/sulphonyl and allyl glucosinolates and OM intake (see Table 3.17). Table 3.4, which lists the concentrations of individual glucosinolates in the crop components shows that only a few individual glucosinolates are present in any particular crop component. Thus, taken with the relationship between individual glucosinolates and voluntary intake given in Table 3.17 suggests that there is a need for further work relating the presence of individual gluconsinolates to voluntary intake before it can be concluded that glucosinolates are an important factor in the low voluntary intakes observed.

TABLE 3.17. Correlation matrix of OM intake and individual glucosinolate concentrations.

	OM intake	GL1	GL2	GL3	GL4	GL5	GL6	GL7	GL9
OM intake									
GL1	-0.7567								
GL2	0.3754	-0.4522							
GL3	-0.8434	0.9306	-0.6437						
GL4	0.4799	-0.4758	0.8209	-0.6830					
GL5	0.2456	-0.3014	0.8629	-0.4326	0.7056				
GL6	0.3654	-0.3399	0.7848	-0.4879	0.8008	0.9318			
GL7	-0.4438	0.1990	-0.2707	0.3761	-0.2475	-0.0778	-0.0717		
GL8	0.4939	-0.4242	0.5554	-0.5778	0.6786	0.2070	0.3587	-0.2538	
GL9	0.4795	-0.2621	0.0293	-0.3417	0.5680	0.0796	0.3601	-0.0138	0.3839

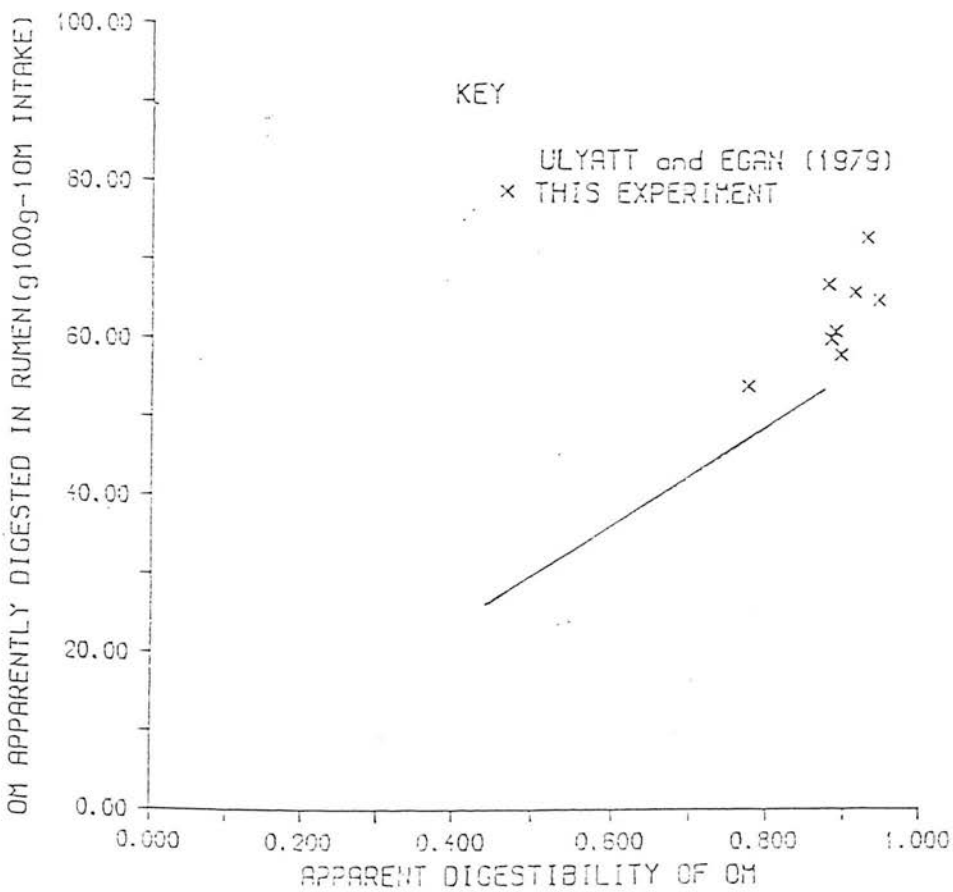
GL1 methyl sulphinyl and/or methyl sulphonyl
GL2 2-hydroxy-3-butenyl
GL3 allyl
GL4 2-OH-pent-4-enyl
GL5 But-3-enyl
GL6 Pent-4-enyl
GL7 3-indole-methyl
GL8 4-methoxy-3-indole methyl and/or phenyl ethyl
GL9 9-1-methoxy-3-indole methyl

OM Flow Rates

The proportions of OM apparently digested in the rumen (Table 3.10) reflect the OM digestibilities of the crops with rape stem having the lowest value (0.54 g OM g^{-1} OM intake) and stubble turnip having the highest (0.73 g OM g^{-1} OM intake). This observation is confirmed by the narrower range of values (0.67 to 0.79 g OM g^{-1} digestible OM intake) when the apparent digestion of OM in the rumen is expressed on a digestive OM intake basis. The only comparable data for forage brassicas is that of Barry et al, (1984) who offered the whole kale plant to 18-month-old wethers. They reported values of 0.66 (s.e., 0023) and 0.73 (s.e., 0.024) for OM apparently digested in the rumen per g OM intake and digestible OM intake respectively, which are similar to those reported for kale in this experiment.

Ulyatt and MacRae (1974) reported much lower amounts of OM apparently digested in the rumen per unit of OM intake with a range from 0.43 to 0.55 g OM g^{-1} OM intake for highly digestible non-brassica herbages. Similar values have also been found by Beever et al (1976), Beever et al (1978) and Cruikshank (1986) for perennial ryegrass and white clover diets. Ulyatt and Egan (1979), using 74 data sets with apparent digestibilities of OM ranging from 0.44 to 0.87, related OM apparent digestibility to OM apparently digested in the rumen (Figure 3.3). Although most of the OM digestibility values from this experiment are higher than those of Ulyatt and Egan (1979), it is apparent that the quantity of OM apparently digested in the rumen of animals fed forage brassicas is higher at a given apparent digestibility of OM than would be predicted for non-brassica diets. Even when expressed on a digestible OM intake basis, the values are higher (0.67 to 0.79 g OM g^{-1} digestible OM intake) for forage brassica diets than those for non-brassica diets

FIGURE 5.3. The relationship between the amount of OM apparently digested in the rumen and OM apparent digestibility of herbages by sheep (after Ulyatt and Egan, 1979)



(0.58 to 0.68 g OM g^{-1} digestible OM intake; Ulyatt and MacRae, 1974).

Using the ratio of 10 g N kg^{-1} microbial OM suggested by Beever et al (1986) it is possible to calculate the true digestion of OM in the rumen, assuming that the proportion of NAN that is microbial in origin is 0.9 and that 0.1 of the resultant microbial N flow past the abomasum are endogenous secretions. The calculated true amounts of OM digested in the rumen per g digestible OM intake were in the range 0.88 to 0.98 for the crop components in this study, and is similar to the value of 0.935 calculated by Beever et al (1986) for non-brassica herbage diets. Thus the higher apparent digestion of OM in the rumen with forage brassica diets is not reflected in the calculated true digestion values when compared to non-brassica diets.

The proportions of NDF apparently digested in the rumen ranged from 0.24 to 0.66. This compares with the values of 0.73 to 0.88 observed by Cruikshank (1986), and of 0.84 to 0.90 observed by Weston and Margan (1979) for digestion of cell wall constituents in other forages. Slightly lower values have been observed in lambs consuming a ground and pelleted roughage/concentrate diet (Margan et al, (1982) but the values observed in this study are lower than in other studies. Barry et al (1984a) suggested that structural carbohydrate and, in particular, hemicellulose digestion in the rumen may be impaired due to the presence of dimethyl disulphide. In this study, very little hemicellulose was present, as seen by the similar NDF and ADF contents, and did not appear to be digested in the rumen. It was calculated that, with the exception of cabbage and stubble turnip leaf, 0.64 to 1.00 of the cellulose was apparently digested in the rumen. This compares with the range 0.83 to 0.97 observed by a number of workers (Ulyatt and MacRae, 1974; Beever et al, 1978; Ulyatt and Egan, 1979).

The apparently greater proportion of structural carbohyrate digested in the hind gut could reflect the digestion of hemicellulose in this organ. However the small amounts of structural carbohyrate present in forage brassica crops and the proportionately high errors associated with these values require that caution is needed in accepting this interpretation.

N Flow Rates

An examination of the NAN flow data (g NAN g^{-1} N intake, Table 3.12) reveals two distinct subsets within the data. The lambs offered the bulb components had a greater ratio of NAN flow rate at the abomasum to N intake (1.20 and 1.33), than, with the possible exception of hybrid turnip (0.96), the lambs offered the leaf and stem components (range 0.66 to 0.82). Rumen ammonia concentrations were also lower for the bulb components (57 to 76 mg l^{-1}) than for the leaf and stem components (161 to 201 mg l^{-1}) (Table 3.13).

Barry et al (1984a) reported a value for whole kale of 0.72 g NAN flowing past the duodenum per g N intake, which was similar to those for the leaf and stem components of kale reported in this experiment. No other data is available for brassica diets. When compared to non-brassica diets, the range observed in this study was similar to that of non-brassica diets of moderate to high digestibility. For example, MacRae and Ulyatt (1974) reported values of 0.63 to 0.94 g NAN flowing past the duodenum per g N intake.

Although the range may be similar to that for non-brassica diets, Barry et al (1984a) observed that the loss of total N across the rumen (total N intake - duodenal total N flow) was over three times greater than the predicted loss for fresh forage diets, using the equation derived by Ulyatt and Egan (1979) and from a knowledge of the N intakes. However the equation does not take any account of the ratio of energy

substrate: N availability in the rumen and this limits the applicability of the equation to the data sets of Ulyatt and Egan (1979). For example, with the bulb components in this study, where total N flow at the abomasum was greater than N intake and rumen ammonia concentrations were low, the predicted N flow rates at the abomasum were smaller than the measured values (Table 3.18). However with the leaf and stem components, where total N flow rates at the abomasum were lower than N intake, and rumen ammonia concentrations were high, the predicted flows were higher than those actually measured. Only with hybrid turnip leaf, where total N flow at the abomasum was the same as N intake was there a similar predicted and measured flow. These observations can be explained in terms of the balance between the supply of energy and N substrates for bacterial growth and does not require that the N digestion of forage brassicas be explained in different terms to that of other forage crops.

The proportion of NAN that was estimated to be microbial in origin (Table 3.14) was in the range 0.84 to 0.93. However, as stated in Section 3.3, these means are derived from a greatly reduced data set due to the microbial fraction of digesta having less counts per unit N than either the whole or precipitate fractions. The most probable explanation for this phenomenon is that there was a capture of the ^{35}S label by soluble organic-S-compounds. These compounds, containing the ^{35}S would then be present in the whole or precipitate fractions, thereby adding to the counts per g N. Possible S containing organic compounds that may have been involved are the breakdown products of glucosinolates and SMCO.

Very little is known about glucosinolate hydrolysis in the rumen but it is assumed that it is similar to that found in <u>in vitro</u> systems and

TABLE 3.18. Predicted (from the equation of Ulyatt and Egan, 1979) and actual flows of total N at the abomasum in Sub-period 2.

Crop component	Predicted*	Actual
Cabbage	12.6	9.8
Hybrid turnip leaf	17.4	17.5
Stubble turnip leaf	17.6	13.3
Rape leaf	18.7	13.1
Kale leaf	19.1	14.3
Barry et al (1984a)	21.6	18.0
Rape stem	10.9	8.9
Kale stem	15.5	12.1
Stubble turnip bulb	11.0	13.9
Swede bulb	10.5	12.0

*$Y = 1.188x - 0.011x^2 - 0.018$ ($r^2 = 0.83$, $n = 30$)

where Y = Flow of total N at the abomasum ($gday^{-1}$)
and X = N intake ($gday^{-1}$)

which is detailed in Figure 2.2. The primary product of glucosinolate hydrolysis is an unstable aglucone which decomposes further to a range of products (Fenwick and Heaney, 1983). In particular it is known that thiocyanates and isothiocyanates are produced after a Lossen-type rearrangement and it is possible during this rearrangement that ^{35}S is incorporated. It is also probable that these thiocyanates and isothiocyanates would not be removed by the addition of barium sulphate, which is added to dilute any inorganic ^{35}S to negligible amounts. This would then lead to higher counts in the whole and precipitate fractions than in the microbial fractions. Dimethyl disulphide, the breakdown product of SMCO, may also have had ^{35}S incorporated into the molecule, as this too is a product of molecular reorganisation. Further investigation of the use of ^{35}S as a microbial marker with forage brassicas is merited and the transfer of the ^{35}S label in the rumen is examined in Appendix Experiment 1.

Dove and McCormack (1986), using the nylon bag technique, estimate N degradability in the rumen to be between 0.75 to 0.83 for rape leaf and stem depending upon the choice of rumen fractional out flow rate N degredability. Values were calculated for this study assuming that 0.2 of the NAN flow past the abomasum was of feed origin. The resultant estimates ranged from 0.82 to 0.88 for leaf and stem components and 0.75 to 0.77 for the bulb components respectively and are comparable with the data of Dove and McCormack (1986).

From the ratios of NAN flow rates to N intake, and the rumen ammonia data (Tables 3.12 and 3.13) it has been argued that, with the lambs offered the bulb components, microbial protein production rate in the rumen is likely to be limited by a supply of available N substrates, whereas with the other crop components, microbial protein production in

the rumen is more likely to be limited by the supply of energy substrates. However, these apparent limitations to microbial protein production in the rumen may not be important in limiting tissue growth in lambs. Using the information collected on digestible OM intakes and NAN passing the abomasum in this experiment, estimates were made as to whether either energy substrate or amino-acid supply would first limit tissue growth in lambs. Maximum empty body weight gains from either the NAN flow date or estimated ME intakes, assuming that all other factors were not limiting, using the derived constants detailed in ARC (1980) and ARC (1984) are given in Table 3.19. Estimated ME intake was derived from digestible OM intake by applying the constant 15.83 used by Beever et al (1986) to the data. An indication that this gives a good estimate of ME intake comes for the close agreement between the predicted ME contents in this study and the ME contents measured by Dewey and Wainman (1984).

TABLE 3.19. Empty body weight gains predicted from NAN flows and estimated ME intakes, assuming no limitations to growth caused by other factors than the one under examination.

	Predicted empty body weight lambs (g day^{-1})	
	NAN Flow	Estimated ME intake
Cabbage	29.8	46.3
Hybrid turnip leaf	191.7	140.7
Stubble turnip leaf	89.4	112.5
Rape leaf	88.7	100.1
Kale leaf	111.5	76.8
Rape stem	0	42.4
Kale stem	64.0	97.8
Stubble turnip leaf	118.1	203.4
Swede bulb	54.0	75.0

Assumptions:- Empty body weight of lambs = 20 kg.

N

1/ Proportion of total microbial N that is amino acid in origin = 0.80.
2/ Absorbability of N in the small intestine = 0.85.
3/ Efficiency of utilisation of absorbed N = 0.80
4/ Tissue maintenance requirement = 350 mg N $kg^{-1}W^{0.75}$
5/ Protein composition of empty body weight gain = 148 g $kg^{-1}W$

ME

1/ ME Intake = 15.83 x DOM intake (MJ).
2/ Maintenance requirement = 260 KJ kg^{-1} $W^{0.75}$.
3/ Efficiency of utilisation of energy for maintenance = 0.72
4/ Efficiency of utilisation of energy for growth = 0.60
5/ Energy composition of empty body weight gain = 13.6MJ $kg^{-1}W$.

In the case of the bulb components the apparent limitation of N supply in the rumen for microbial protein production was predicted to result in a limitation in NAN supply for tissue gain since higher gains were prediced from the ME intakes than from the NAN flow rates at the abomasum. The leaf and stem components, with the exception of hybrid turnip and kale leaf, also were predicted to have higher tissue gains associated with ME intakes than with NAN flows at the abomasum. However the higher rumen ammonia concentrations observed, together with the lower NAN flow rates per unit N intake suggest that N substrates were not limiting microbial protein production, and more probably a limitation in energy substrate supply in the rumen for microbial protein production limited tissue gain. The tissue gain predicted from hybrid turnip and kale leaf components suggested that they were limited by ME intake since higher gains were associated with the NAN flows at the abomasum.

Conclusion

This experiment provided a description of the intake and digestion of forage brassicas from which the following conclusions are drawn:-

1/ Leaf, stem and bulb components of forage brassicas have uniformally high apparent digestibility values associated with a low structural carbohydrate content. The proportion of OM apparently

digested in the rumen per g OM intake and per g digestible OM intake were higher than that found with non-brassica herbage diets.

2/ Voluntary intakes are lower than would be predicted from their high digestibility values using relationships developed from non forage brassica crops. Possible reasons for the low voluntary intakes include high VFA production rates influencing chemostatic feed back mechanism of intake control, the presence of foam in the rumen causing physical distension of the rumen and the action of the breakdown products of glucosinolates inhibiting intake directly or indirectly. The effects of foam and glucosinolates on voluntary intakes will be examined further in Experiments 5 and 6 respectively.

3/ N digestion of forage brassicas was similar to that for non-brassica herbage diets. Microbial protein production rate of leaf and stem components appeared to be limited by energy substrate supply and the bulb components by the availability of N substrates in the rumen. This is examined further in Experiment 2 in which the effect of supplementation of leaf crops on the amounts of NAN passing the abomasum are measured.

4/ From the NAN flow rates at the abomasum and the estimated ME intakes, it is predicted that supplementation of bulb components with a rumen-degradable protein source would increase empty body weight gain. With the leaf and stem components, the provision of a supplementary energy would increase tissue gain. These predictions will be evaluated further in Experiments 3 and 4.

5/ The use of ^{35}S to measure microbial protein production rate appeared inappropriate with forage brassica diets. The fate of ^{35}S in the rumen of lambs given forage brassicas will be examined further in Appendix Experiment 1.

CHAPTER 4 - EXPERIMENT 2

THE EFFECT OF CEREAL SUPPLEMENTATION ON THE DIGESTION OF OM AND N IN LAMBS OFFERED LEAF COMPONENTS OF FORAGE BRASSICAS

INTRODUCTION (Section 4.1)

The previous experiment suggested that in lambs offered the leaf components of forage brassicas microbial protein production and thereby tissue gain was limited by the availability of energy substrates in the rumen. The objective of this experiment was to test this hypothesis, using a cereal supplement as the energy substrate, under similar conditions to those of Experiment 1.

The review of literature (Chapter 2) showed that cereal supplementation had produced variable effects on lamb performance in lambs offered forage brassicas with Fitzgerald (1983) attributing this to high substitution rates of the supplement for the crop. In this experiment the intakes of forage brassica leaf were fixed so that comparisons of flows of OM from the rumen in lambs given supplement with those not supplemented would not be confounded with differences in the level of DM intake. Rape and hybrid turnip leaf were chosen as the test forage brassicas since the discussion of Experiment 1 suggested that the supply of energy substrates to lambs offered these brassica components limited ruminal microbial protein production. Hybrid turnip leaf was also chosen as the results of Experiment 1 suggested that NAN flows per g N intake were higher for this crop than the other leaf crops and therefore it might not respond to energy supplementation in a similar manner to the other leaf components. The level of supplement was taken as 150 g DM day^{-1}, this being calculated to provide approximately one fifth of the animals daily metabolisable energy requirements.

MATERIALS AND METHODS (Section 4.2)

Treatment and Experimental Design

The effect of a barley supplement on the digestion in the rumen of the leaf components of two forage brassica crops, rape (cv. Lair) and hybrid turnip (cv. Tyfon), were compared with 12 lambs in an incomplete 4 x 4 latin square design. There were three squares and the last period in each square was omitted. The periods were of three weeks duration and the treatments are detailed below.

Treatment

A	Rape leaf
B	Rape leaf + 150 g DM day^{-1} barley supplement
C	Hybrid turnip leaf
D	Hybrid turnip leaf + 150 g DM day^{-1} barley supplement

The experiment was conducted between October and December, 1984 at the Hill Farming Research Organisations Hartwood Research Station, Shotts, Lanarkshire.

Animals

Twelve Scottish Blackface weather lambs, aged five months and weighing 28.7 (s.e. = 0.42)kg at the start of the experiment were obtained from the Hill Farming Research Organisation's Sourhope Research Station, Yetholm, Roxburgh, in early August. In late August, each was prepared with a cannula in the rumen and a simple 'T-shaped' cannula in the abomasum, as described in Experiment 1 (Section 3.2). The lambs were offered dried grass pellets ad libitium until the start of the experiment in early October.

The lambs were dosed with 1 g of copper needles in early July. At the beginning of September, they received a clostridium/pneumonia

vaccination (Heptavic-P, Hoescht) and were dosed with Fenbendazole (Panacur, Hoescht). This was repeated six weeks later in mid-October at the end of period 1.

Experimental procedures

In a pre-experimental period of one week, the lambs were offered rape leaf ad libitum. The lambs were then ranked according to voluntary intake and allocated to high, medium and low intake squares. Within each square, the lambs were randomly allocated to a treatment sequence. Intakes were then restricted to 0.85 of the mean voluntary intake of DM for each square. The same intakes of forage brassica leaf were used in each of the three periods. The mean intakes of DM for each square were 369, 321 and 221 g DM day^{-1} for the high, medium and low intake squares respectively. In addition to the intake of forage brassica components, 150 g DM day^{-1} rolled, pelleted barley was offered to the lambs on treatment B and D.

Feeds

An area (0.25 ha) was sown with hybrid turnip (cv. Tyfon) and rape (cv. Lair) on June 4, 1984, at a seed rate of 6.60 kg^{-1} with 625 kg^{-1} of a 22:11:11 compound fertiliser being applied to the seed bed. The leaf material was obtained daily. The whole hybrid turnip plant was harvested manually and the leaf was separated from the bulb by hand. The rape leaf component, which was taken to be all the plant tissue above the first node, was harvested using secateurs to avoid the stem being harvested with the leaf component. Prior to feeding, the leaf components were chopped into approximately 4 cm lengths, using a chaff cutter. A sample was taken daily for DM determination (oven dried at 80°C for 24h). A further sample was bulked over each sub-period, sub-sampled, stored at -20°C, freeze dried, ground and then analysed for

OM, N, NDF, ADF, ADL, SMCO and total glucosinolate concentrations.

The rolled, pelleted barley was offered to the lambs at 0815h. The crop component was then offered at 0830h (after all the supplement had been consumed) and at 1630h. Any refusals were collected at 0800h.

Measurements

In the second week of each period (sub-period 1) measurements were made of the apparent digestibility of OM, OM, N and NDF and N excretion in the urine using the same procedures as described in Section 3.2.

In the third week of each period (sub-period 2) measurements were made of digesta flow rates at the abomasum with estimates of DM, OM, total N and NAN flow rates being made. Techniques used were similar to those described in Section 3.2 except that in periods 1 and 2, non radioactive Ruthenium phenethroline and Chromium-EDTA were used as digesta markers. The Chromium-EDTA was prepared using the method of Binnerts et al (1968), modified by the addition of 44 g NaOH to neutralise the solution after the addition of $CaCl_2$. Ruthenium phenethroline was infused at the rate of 55 mg day^{-1} and the Chromium-EDTA was infused at the rate of 400 mg day^{-1}.

The samples of abomasal contents were processed according to the same scheme outlined in Figure 3.1 except that, instead of the fractions being counted for radioactivity, the Ruthenuim and Chromium concentrations were determined on freeze dried material by X-ray fluorescence spectrometry (PW1212, Phillips, Cambridge), as outlined by Evans et al (1977). In period 3, ^{103}Ruthenium phenathroline and ^{51}Chromium-EDTA were infused at the rates of 10 μCi and 50 μCi per day, respectively.

Rumen samples for ammonia and VFA concentrations were taken at 1000h, 1400h, 1800h, 2130h, 0000h and 0700h on the same days as when abomasal samples were taken and were analysed separately by the same methods as described in Section 3.2.

Statistical Analysis

Statistical analysis was performed using the regression analysis sub-program of GENSTAT (Release 4.04B, Lawes Agricultural Trust, Rothamstead Experimental Station, 1984). Initially, the overall mean for each variable was estimated. A regression model was then fitted to the unbalanced data with the factors of square, sheep, period, treatment and interactions between these factors being included in the model. From this model, estimates of treatment effects and their interactions were obtained and these are given, together with the s.e. of the estimate, in the tables of results (Section 4.3). Estimates of treatment means were then constructed using these regression estimates and the overall variate mean.

RESULTS (Section 4.3)

The chemical composition of the crop components and supplement offered in sub-periods 1 and 2 are given in Tables 4.1 and 4.5 respectively. Hybrid turnip leaf had a lower DM (80-98 g kg^{-1}) and higher ash content (149-201 g kg^{-1}DM) than the DM (106-126 g kg^{-1}) and ash (110-129 g kg^{-1} DM) contents of rape leaf. However they had similar N, structural carbohydrate, SMCO and total glucosinolate contents. As the experiment progressed, DM content in both leaf components increased and total glucosinolate content showed a slight decrease. SMCO content in rape leaf increased with time, whereas the SMCO content of hybrid turnip leaf declined with time.

There was no significant interaction between squares (level of

TABLE 4.1. Chemical description of plant species offered in Sub-period 1

		DM ($g kg^{-1}$)	Ash ($g kg^{-1}$ DM)	N ($g kg^{-1}$ DM)	NDF ($g kg^{-1}$ DM)	ADF ($g kg^{-1}$ DM)	ADL ($g kg^{-1}$ DM)	SMCO ($g kg^{-1}$ DM)	Total glucosinolate ($mg 100g^{-1}$)
Rape leaf	Period 1	106	128	36.9	194	161	13.6	6.8	12.0
	Period 2	114	120	40.8	192	185	13.2	8.4	10.8
	Period 3	126	113	36.5	178	156	8.7	10.0	10.0
Hybrid turnip leaf	Period 1	92	168	37.9	204	185	14.6	8.8	12.5
	Period 2	92	195	33.5	168	153	10.3	7.8	11.3
	Period 3	98	198	41.2	183	182	11.3	8.1	9.5
Barley		851	32	15.5	199	57	7.5	-	-

intake) and treatments for any variable and consequently only treatment means are given. Due to various reasons, 0.3, 0.2 and 0.5 of the data sets in periods 1, 2 and 3 respectively were omitted from the analysis. This was mainly due to problems of inappetance.

Sub-Period 1. Although unsupplemented and supplemented lambs were offered the same amounts of plant material throughout the experiment, it was not always totally consumed leading to small differences in intake between the treatments. The barley supplement was always totally consumed. The intake and apparent digestibility of DM for the two plant components and supplement treatments are given in Table 4.2. The apparent digestibility of the DM of the rape leaf was significantly ($P < 0.01$) higher than that of hybrid turnip leaf (0.852 vs. 0.802) and supplementation did not affect the apparent digestibility of DM. Because of the higher ash content of the hybrid turnip leaf, the OM intake of hybrid turnip leaf was significantly ($P < 0.001$) lower than that of the rape leaf (290 vs 362 gOM day^{-1}) (Table 4.3) There was no significant ($P > 0.05$) difference in apparent digestibility of OM between plant species or supplements but the apparent digestibility of NDF in rape leaf (0.770) was significantly ($P < 0.001$) higher than that in hybrid turnip leaf (0.602).

The intake, apparent digestibility and losses in urine of N are given in Table 4.4. The lambs given hybrid turnip leaf had a lower N intake than those given rape leaf (14.1 vs 15.7 g N day^{-1}, $P < 0.05$). There was no significant difference between either plant species or supplement treatments in apparent digestibility of N but lambs given hybrid turnip leaf had a significantly ($P < 0.05$) higher loss of N in urine than lambs given rape leaf (10.9 vs 8.8 g N day^{-1}).

Sub-Period 2. The intakes and flows of DM and OM at the abomasum

TABLE 4.2. The intake and apparent digestibility of DM of plant species and supplements by lambs in Sub-Period 1.

		Crop intake of DM ($gDMday^{-1}$)	Total intake of DM ($gDMday^{-1}$)	Apparent digestibility of DM
Rape leaf	0	396	396	0.844
	B	405	560	0.860
Hybrid turnip leaf	0	385	385	0.810
	B	357	512	0.794
Regression constants				
Plant species		-30	-30	-0.049**
	s.e.	16.5	16.5	0.0143
Supplement		- 9	141***	0.000
	s.e.	19.2	19.2	0.0143
Plant species.supplement		-38	-38	-0.03
	s.e.	34.7	34.7	0.0298

0 - no supplement
B - supplement (150g DM day^{-1} pelleted rolled barley)

TABLE 4.3. The intake of OM and apparent digestibility of OM and NDF of plant species and supplements by lambs in Sub-Period 1.

		Crop intake of OM ($gOMday^{-1}$)	Total intake of OM ($gOMday^{-1}$)	Apparent digestibility of OM	Apparent digestibility of NDF
Rape leaf	0	359	359	0.889	0.770
	B	365	512	0.893	0.770
Hybrid turnip leaf	0	292	292	0.877	0.622
	B	289	443	0.857	0.582
Regression constants					
Plant species		-71***	-71***	-0.022	-0.167***
	s.e.	13.6	13.6	0.0137	0.0226
Supplement		1	146***	-0.009	-0.021
	s.e.	13.2	13.2	0.0137	0.0308
Plant species.supplement		- 9	- 9	-0.025	-0.03
	s.e.	24.0	24.0	0.0285	0.0558

TABLE 4.4. Intake and apparent digestibility of N and N losses in urine by lambs in Sub-period 1.

		Crop intake of N	Total intake of N	Apparent digestibility	N loss in urine
Rape leaf	0	15.7	15.7	0.867	7.88
	B	15.7	18.0	0.869	9.68
Hybrid turnip leaf	0	14.5	14.5	0.869	11.01
	B	13.7	16.2	0.819	10.74
Regression constants					
Plant species		-1.6*	-1.6*	-0.023	2.10*
	s.e.	0.68	0.68	0.0174	0.874
Supplement		0.4	1.9*	-0.024	0.76
	s.e.	0.58	0.58	0.0202	0.855
Plant species.supplement		0.7	-0.7	-0.052	-2.09
	s.e.	1.20	1.20	0.0365	1.770

TABLE 4.5 Chemical description of plant species offered in Sub-period 2

		DM (gKg^{-1})	Ash (gKg^{-1} DM)	N (gKg^{-1} DM)	NDF (gKg^{-1} DM)	ADF (gKg^{-1} DM)	ADL (gKg^{-1} DM)
Rape leaf	Period 1	113	129	34.9	193	177	9.9
	Period 2	119	125	41.3	182	166	7.6
	Period 3	116	110	39.8	169	138	8.2
Hybrid turnip leaf	Period 1	80	186	35.4	211	191	16.7
	Period 2	89	201	36.6	224	198	13.0
	Period 3	96	149	42.5	167	154	9.9

of lambs are given in Tables 4.6 and 4.7 respectively. In contrast to sub-period 1, lambs given rape leaf had significantly ($P < 0.001$) lower intakes of DM than lambs given hybrid turnip leaf (328 vs 409 g DM day^{-1}) because of a higher level of refusal but, due to the higher ash content of hybrid turnip leaf, there was no significant difference between the intakes of OM of the plant species (Table 4.7). The lambs given hybrid turnip leaf had a significantly ($P < 0.001$) higher flow of OM past the abomasum than the lambs given rape leaf (175 vs 132 g OM day^{-1}), although the difference was not significant when expressed per unit OM intake.

There was a significantly ($P < 0.05$) lower intake of OM of both plant species when supplements were given (333 vs 299 g OM day^{-1}), although total intakes of OM were significantly ($P < 0.001$) higher in the supplemented treatments. The flows of OM at the abomasum were significantly ($P < 0.01$) higher in the supplemented treatments (164 g OM day^{-1}) compared to unsupplemented treatments (143 g OM day^{-1}). However there was no significant difference between unsupplemented and supplemented treatments in OM flows at the abomasum when expressed per unit OM intake although there was a trend for lower values in the supplemented treatments compared to the unsupplemented treatments. There were significantly ($P < 0.001$) higher amounts of OM apparently digested in the rumen in supplemented (280 g OM day^{-1}) compared to unsupplemented (191 g OM day^{-1}) treatments (Table 4.8). The proportion of digestible OM apparently digested in the rumen was significantly ($P < 0.01$) higher in supplemented treatments (0.70) compared to unsupplemented treatments (0.63).

The intakes and flows at the abomasum of total N in lambs given the two crop and supplement treatments are shown in Table 4.9. The lambs given hybrid turnip leaf had a significantly ($P < 0.01$)

TABLE 4.6. Intake and flow at abomasum of DM in lambs given plant species and supplement in Sub-period 2.

		Crop intake of DM ($gDMday^{-1}$)	Total intake of DM ($gDMday^{-1}$)	DM flow at abomasum $gDMday^{-1}$)	DM flow at abomasum per unit DM intake
Rape leaf	0	347	347	193	0.55
	B	310	460	206	0.48
Hybrid turnip leaf	0	425	425	213	0.52
	B	393	543	266	0.52
Regression constants					
Plant species		81***	81***	40**	0.01
	s.e.	20.4	20.4	13.3	0.033
Supplement		-34	116**	33*	-0.03
	s.e.	17.6	17.6	12.2	0.034
Plant species.supplement		5	5	40	0.07
	s.e.	33.6	33.6	23.4	0.055

TABLE 4.7. Intake and flow at abomasum of OM in lambs given plant species and supplement in Sub-period 2.

		Crop intake of OM ($gOMday^{-1}$)	Total intake of OM ($gOMday^{-1}$)	OM flow at abomasum ($gOMday^{-1}$)
Rape leaf	0	320	320	119
	B	280	425	145
Hybrid turnip leaf	0	347	347	166
	B	319	464	183
Regression constants				
Plant species		33	33	43***
	s.e.	16.3	16.3	9.8
Supplement		-34*	111***	21**
	s.e.	15.1	15.1	8.5
Plant species.supplement		12	12	-9
	s.e.	28.8	28.8	16.1

TABLE 4.8. Apparent digestion of OM in the rumen of lambs given plant species and supplement in Sub-period 2.

		Apparent digestion of OM in rumen ($gOMday^{-1}$)	Proportion of OM intake apparently digested in rumen	Proportion of digestible OM apparently digested in rumen
Rape leaf	0	201	0.59	0.66
	B	280	0.63	0.70
Hybrid turnip leaf	0	181	0.52	0.61
	B	281	0.59	0.71
Regression constants				
Plant species		5	-0.05	-0.04
	s.e.	14.4	0.026	0.035
Supplement		80***	0.06	0.09**
	s.e.	16.3	0.030	0.031
Plant species.supplement		4	0.03	0.10
	s.e.	25.6	0.046	0.059

TABLE 4.9. Intake and flow at abomasum of total N in lambs given plant species and supplement in Sub-period 2.

		Crop intake ($gNday^{-1}$)	Total N intake ($gNday^{-1}$)	Total N flow at abomasum ($gNday^{-1}$)
Rape leaf	0	13.45	13.45	8.33
	B	11.81	14.13	8.09
Hybrid turnip leaf	0	16.43	16.43	9.19
	B	15.23	17.55	11.75
Regression constants				
Plant species		3.20**	3.20**	2.26**
	s.e.	0.911	0.911	0.739
Supplement		-1.41	0.91	1.16
	s.e.	0.731	0.731	0.653
Plant species.supplement		0.43	0.43	2.79
	s.e.	1.390	1.390	1.250

higher intake of N than the lambs given rape leaf (15.8 vs 12.6 g N day^{-1}) and this was associated with significantly ($P < 0.01$) higher flows of total N and NAN (Table 4.10) at the abomasum for the hybrid turnip leaf (9.8 g NAN day^{-1}) than with the rape leaf (7.5 g NAN day^{-1}). However differences in total N and NAN flow rates disappeared when the NAN flow data were expressed per unit of N intake (Table 4.10). There was no significant ($P > 0.05$) difference in N intake between supplemented and unsupplemented treatments and there was no significant ($P > 0.05$) difference in total N or NAN flows at the abomasum. However there was a significant ($P < 0.05$) crop x supplement interaction with the supplement inceasing total N and NAN flows in lambs given hybrid turnip leaf but not in lambs given rape leaf.

Figure 4.1 describes the pattern of rumen ammonia concentration over 24 hours in lambs given the four treatments. There was no significant ($P > 0.05$) differences between either the plant species or supplement treatments at any of the times. However the effect of supplementation was to delay and significantly ($P < 0.05$) reduce the magnitude of increase in rumen ammonia concentration between 1400h and 1800h and 1800h and 2130h. Figures 4.2, 4.3 and 4.4 describe the pattern of ruminal VFA concentration of acetate, propionate and butyrate over 24h. There was no significant ($P > 0.05$) effects of plant species on acetate, propionate or butyrate concentration. However as a proportion of the total VFA concentrations, hybrid turnip leaf had a significantly ($P < 0.05$) lower proportion of acetate (0.649 vs 0.681) and significantly ($P < 0.05$) higher proportion of propionate (0.220 vs 0.188). The effect of supplementation was to reduce the proportion of acetate (0.647 vs 0.683; $P < 0.01$) in the rumen. At 1000h the lambs given supplement had significantly ($P < 0.05$) higher propionate and butyrate

TABLE 4.10. Flow at abomasum of NAN in lambs given plant species and supplement in Sub-period 2.

		NAN flow at abomasum ($gNday^{-1}$)	gNAN flow at abomasum per g N intake
Rape leaf	0	7.75	0.58
	B	7.31	0.56
Hybrid turnip leaf	0	8.55	0.53
	B	11.07	0.66
Regression constants			
Plant species		2.28**	0.03
	s.e.	0.698	0.049
Supplement		1.04	0.05
	s.e.	0.616	0.050
Plant species.supplement		2.98*	0.15
	s.e.	1.180	0.077

FIGURE 4.1. The concentration of ammonia (mgl^{-1}) in the rumen of lambs given forage brassica crops plus supplements

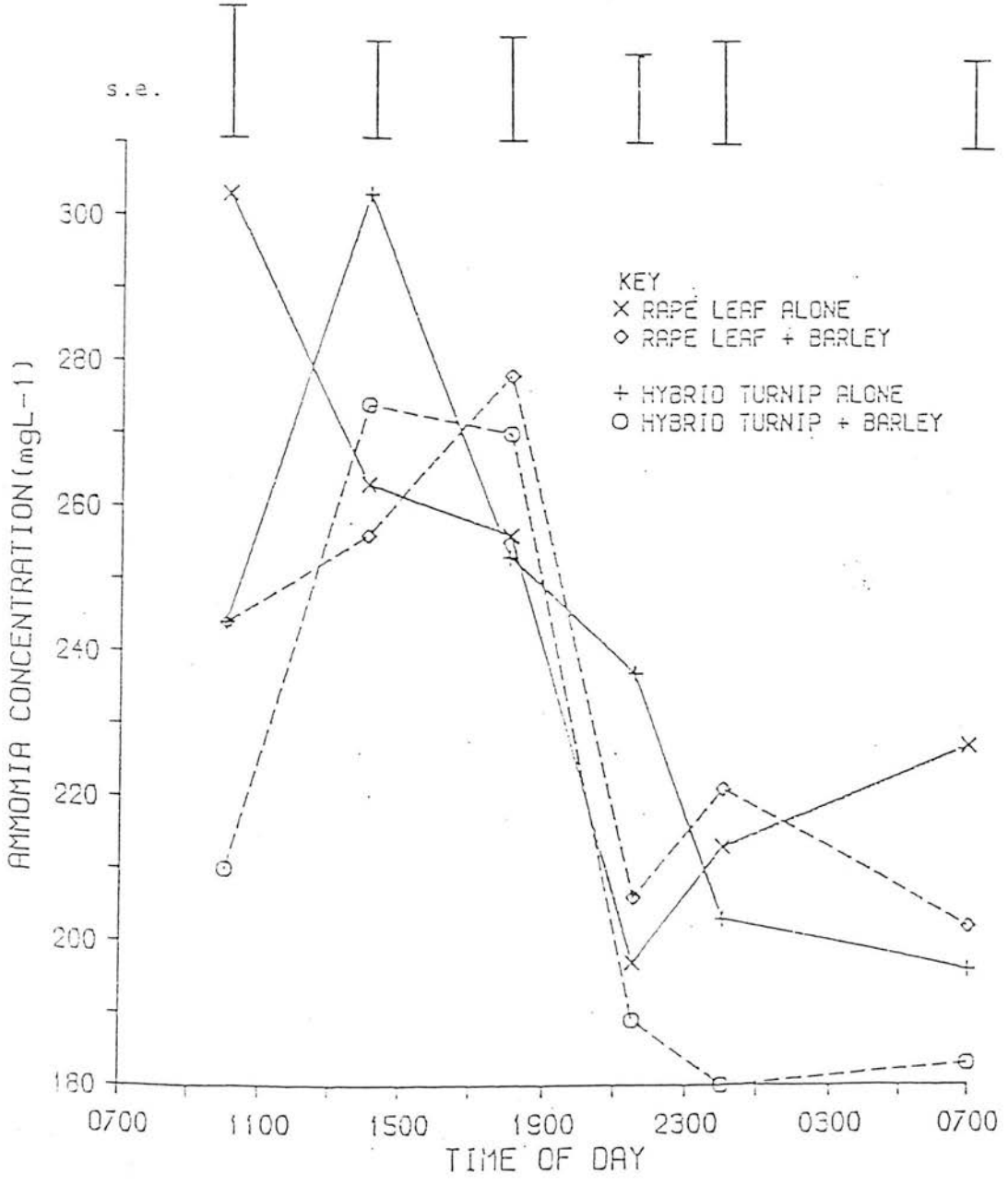


FIGURE 4.2. The concentration of acetate ($mmol\,l^{-1}$) in the rumen of lambs given forage brassica crops plus supplements

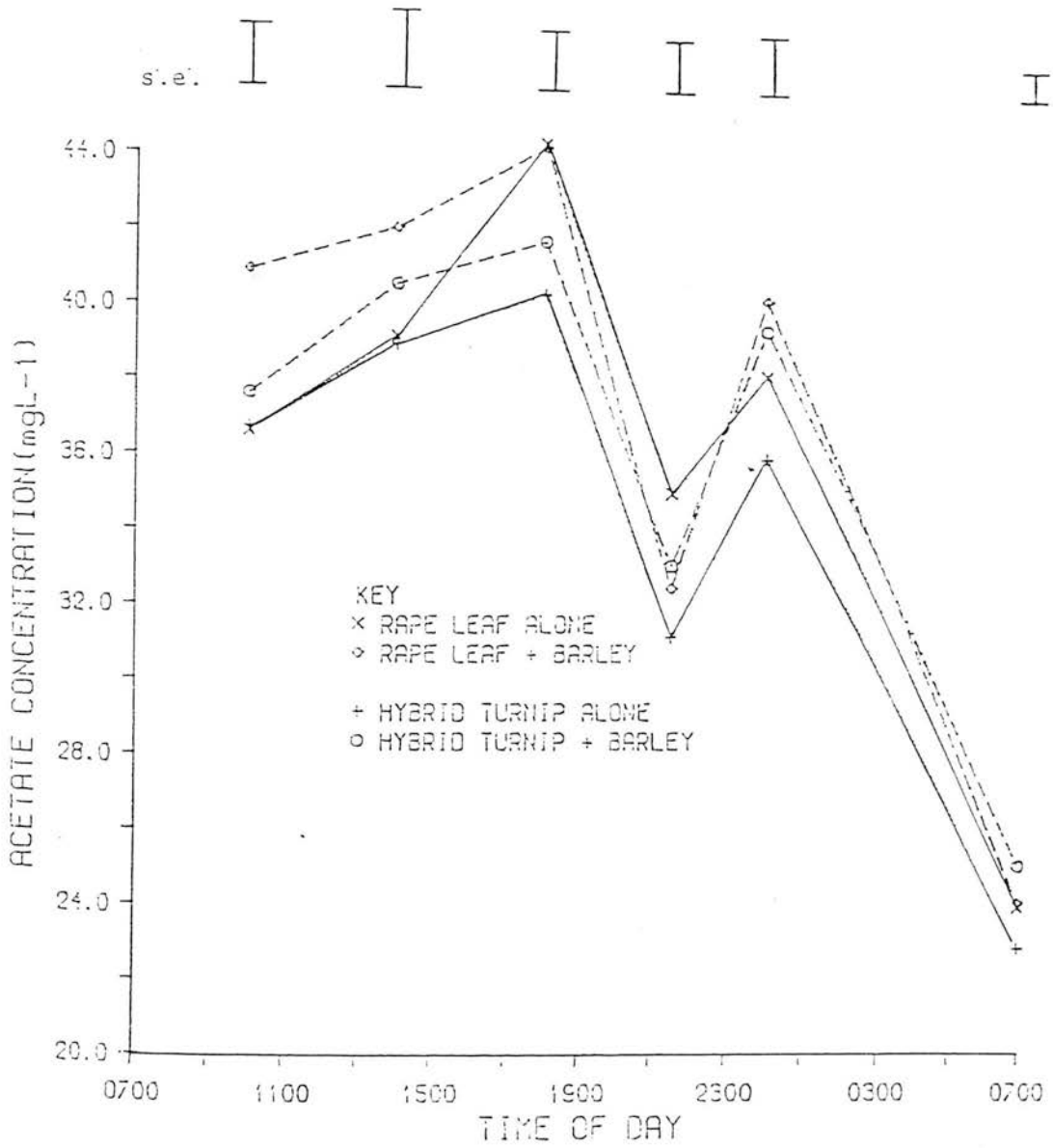


FIGURE 4.3. The concentration of propionate ($mmol\,l^{-1}$) in the rumen of lambs given forage brassica crops plus supplements

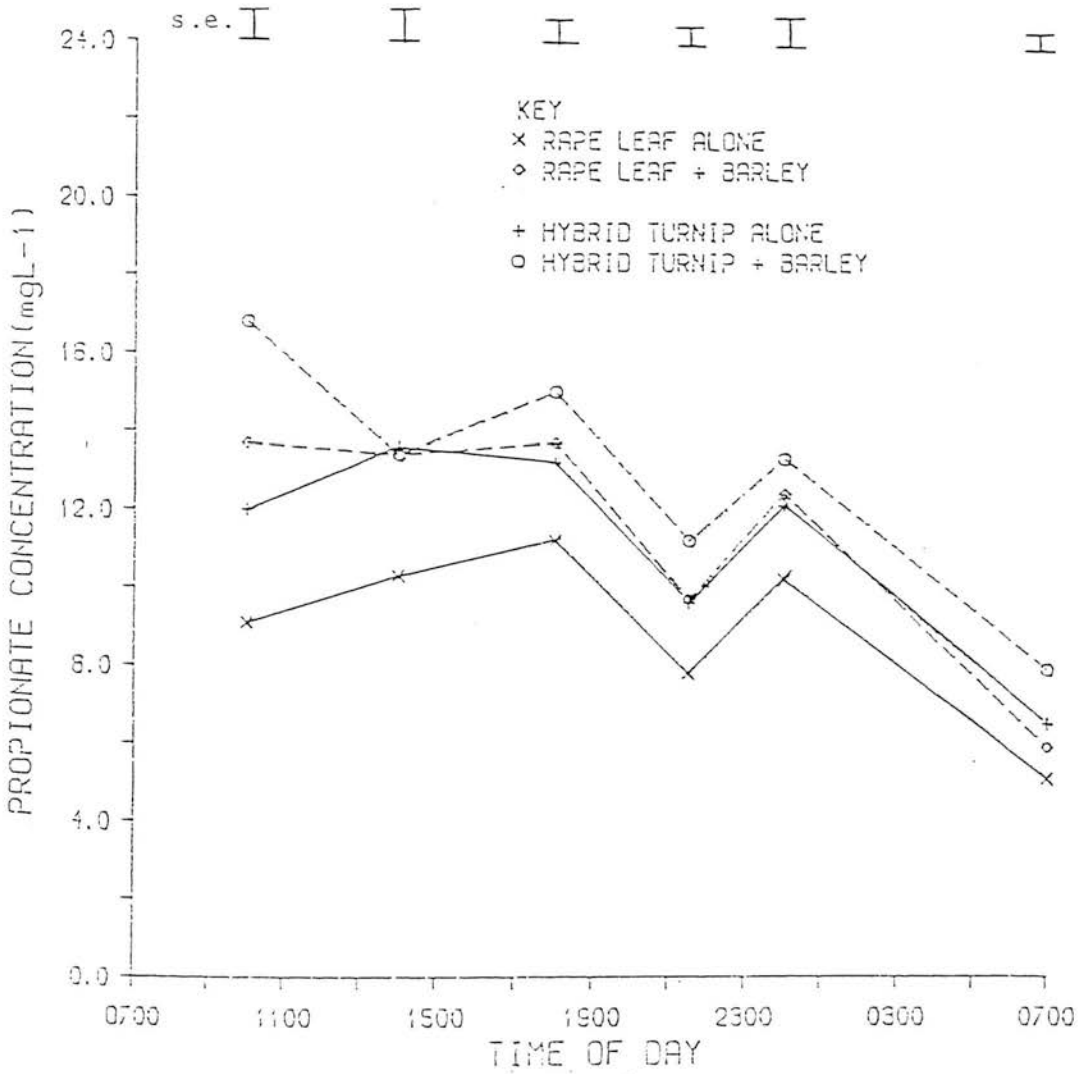
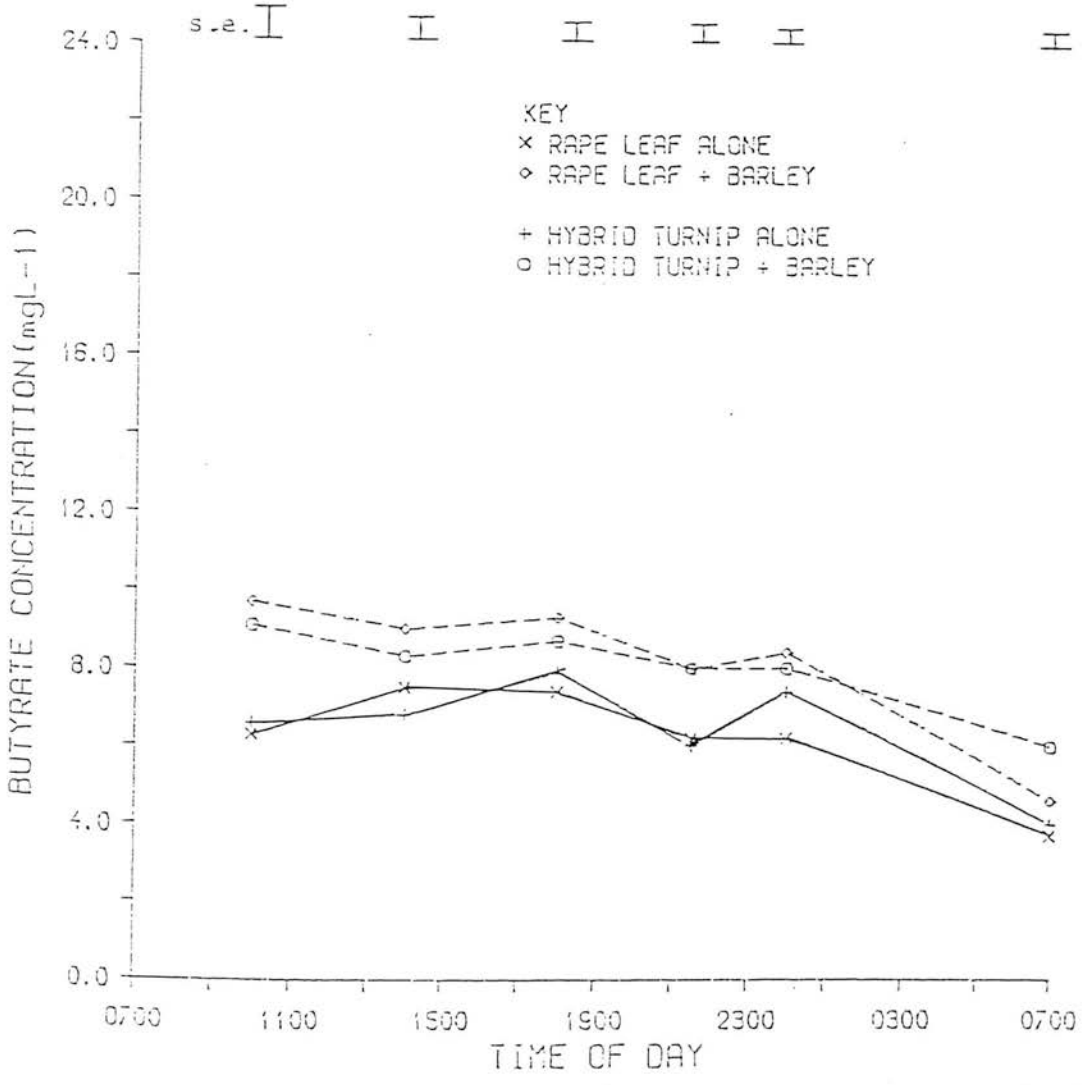


FIGURE 4.4. The concentration of butyrate ($mmol\,l^{-1}$) in the rumen of lambs given forage brassica crops plus supplements



concentrations than lambs given no supplement but there was no effect of treatments at other times.

The data for individual animals used to derive all the means in this experiment is given in Appendix Tables 4.1, 4.2 and 4.3.

DISCUSSION (section 4.4)

The objective of this experiment was to characterise the effects of a predominantly energy supplement, viz. barley, on the N flows at the abomasum of sheep fed two forage brassica leaf diets, in order to test the hypothesis that the supply of energy substrate limits microbial protein production rate in the rumen such that barley supplementation would increase the flow of NAN at the abomasum. The experiment was designed such that substitution of the crops by barley would not be a confounding issue.

The chemical description of the plant species, detailed in Tables 4.1 and 4.5, showed a wide variation between both periods and sub-periods. It has been shown that factors such as rainfall (Sheldrick et al, 1981), sowing date and therefore plant maturity (Harper and Compton, 1980; Bradshaw, 1981), plant density (Bradshaw, 1981) and soil conditions (Bradshaw et al, 1982) contribute to differences in chemical composition. As some of these factors varied over the area of the crops and over the period used for harvesting the crops, it is perhaps not unexpected that there were differences in chemical composition throughout the experiment.

Plant Species

There was no difference between the plant species in apparent digestibility of OM or N. However hybrid turnip leaf had a significantly ($P < 0.001$) lower apparent digestibility of NDF than rape leaf. Although both plant species had similar NDF contents, the proportion of ADL in

the NDF was higher in hybrid turnip leaf than in the rape leaf, which may offer some explanation for the lower values of digestibility of NDF of the hybrid turnip leaf. The lower apparent digestibility of NDF also offers a partial explanation for the significantly ($P < 0.001$) higher flows of OM at the abomasum with hybrid turnip leaf (166 g OM day^{-1}) compared to rape leaf (119g OM day^{-1}), although these differences just failed to reach significance when expressed per g OM intake. The proportion of acetate in the total VFA concentration in the rumen was also lower with hybrid turnip, perhaps associated with reduced digestion of NDF in the rumen.

The digestion of N with both plant species was similar since there was no differences in total N or NAN flows at the abomasum when expressed per g N intake. The higher losses of N in the urine per g N intake implies a less efficient capture of N in the rumen with hybrid turnip leaf. However this was not reflected in significantly lower NAN flows at the abomasum per unit N intake or higher rumen ammonia concentrations.

Supplementation

Apparent digestibilities of OM, N and NDF were similar for both supplemented and unsupplemented lambs. The effect of supplementation in both plant species was to significantly ($P < 0.01$) increase the proportion of digestible OM apparently digested in the rumen and this was more evident in lambs given hybrid turnip leaf than rape leaf. There are two possible explanations for this finding. The first is that a greater proportion of OM in the barley was digested in the rumen than that of the forage brassica. The second is that the supplement provided a better balance of substrates in the rumen which increased the extent of digestion of the herbage in the rumen. This latter explanation is

consistent with the suggestion of a greater effect of supplementation and apparent digestion of OM in the rumen with hybrid turnip leaf than with rape leaf. However, the reduced concentration of acetate as a proportion of the total VFA concentration in the rumen on the supplemented treatments would favour the former explanation.

The effects of supplementation on NAN flow rates were slightly different for the two plant species. In lambs given rape leaf there was no effect of supplementation on NAN flow rates. However, in lambs given hybrid turnip leaf the effect of barley supplementation was to significantly ($P < 0.05$) increase NAN flow at the abomasum. Although a similar trend was apparent when expressed per g N intake the differences just failed to reached statistical significance.

It was expected that the two brassica species would behave similarly to energy supplementation, since the results from Experiment 1 suggested that microbial protein production and hence NAN flow at the abomasum for both plant species was likely to be limited by the supply of energy substrates in the rumen. In comparison to Experiment 1 (Chapter 3), the voluntary intakes of OM for this studies were 0.60 of those in Experiment 1, although the apparent digestibility values were similar. The chemical composition of rape leaf in both experiments was also similar as was the digestion of OM and N in the rumen. The hybrid turnip leaf in this experiment had a higher N concentration than that in Experiment 1 and consequently N intakes were similar in both experiments. However the NAN flows at the abomasum for the hybrid turnip leaf were much lower in this experiment.

When the N intake data is expressed as a proportion of the OM apparently digested in rumen, the values for rape leaf were similar in both experiments (0.06 vs 0.07). The proportion for hybrid turnip leaf in

Experiment 1 was 0.05 whilst in this experiment it was 0.09, the value dropping to 0.06 following supplementation. However even with the supplemented treatments in this experiment there appeared to be less energy substrate available in the rumen, as indicated by the amounts of OM apparently digested in the rumen, to capture the potentially available N. This offers an explanation for the lower NAN flows at the abomasum than in Experiment 1 for hybrid turnip leaf. The suggestion therefore that microbial protein production in the rumen is limited by the availability of energy substrates is probably still valid, as seen by the increased NAN flow rate with energy supplementation of the hybrid turnip leaf. For the rape leaf, the N intake as a proportion of OM apparently digested in the rumen was reduced from 0.07 to 0.05 with the barley supplementation, but as the proportion in Experiment 1 was 0.06, this offers an explanation why there was a lack of response in NAN flows at the abomasum to supplementation in this experiment.

The implications of the above arguments are that the method and type of supplement and possibly its level were not optimum for the capture of the N potentially available in the rumen. In this experiment when the supplement was given once daily, it is probable that the supplement was rapidly digested in the rumen, as indicated by the sharp peak in propionate concentration in the rumen (see Figure 4.3) after feeding, whilst, although there was a release of ammonia into the rumen at the same time, as demonstrated by the higher ruminal ammonia concentrations, the decline over 24 h of ruminal ammonia concentrations was similar with supplemented and unsupplemented treatments. The consequence of this is that N capture in the rumen may not have been improved. A more constant release of energy substrate in the rumen might have overcome this problem. The apparent efficiency of N

capture, assuming the proportion of N in the total diet digested in the rumen remained constant, was significantly ($P < 0.001$) reduced by supplementation (53 vs 34 gNAN flow at the abomasum kg^{-1}OM apparently digested in the rumen) and this suggests that attempts to increase the level of energy substrates in the rumen with the current feeding regime would be of doubtful biological or economic efficiency.

CHAPTER 5 - EXPERIMENT 3

THE EFFECT OF THREE FORMS OF SUPPLEMENTATION ON THE INTAKE AND TISSUE GAIN IN LAMBS GRAZING THE LEAF COMPONENTS OF TWO FORAGE BRASSICA CROPS

INTRODUCTION (Section 5.1)

In Experiment 2, the effects of a cereal supplementation on the digestion of OM and N in lambs offered two leaf components of forage brassica were examined. The results were not inconsistent with the hypothesis of Experiment 1 that microbial protein production in lambs offered leaf components was limited by the supply of energy substrates, although this was less obvious with the rape leaf diet than the hybrid turnip leaf diet. The objective of this experiment was to test further the hypothesis set up in Experiment 1, by measuring tissue gains of lambs grazing forage brassica leaf crops and offered three supplements. The same two leaf components as used in Experiment 2 were also used in this experiment and, as the two experiments were conducted concurrently, it was envisaged that the results of one experiment could be applied directly to the other.

In this experiment the intake of forage brassica leaf was measured as it was expected that a knowledge of substitution rates could be important in interpreting the effects of supplementation on tissue gain. Two methods of measuring the intake of grazing lambs were used since apparent difficulties had been experienced in previous experiments in the measurement of intake (Dove et al, unpublished data; Armstrong et al, 1984).

The level of supplement offered was set at the same amount offered to lambs in Experiment 2. A barley/soya bean meal supplement was included to confirm the hypothesis that tissue gain in lambs grazing the forage crops was not limited by a rumen-degradable N supply. A

dried molassed sugar beet pulp supplement was included to compare the effects on tissue gain of a predominantly sugar source of energy with that of a starch source of energy, barley.

MATERIALS AND METHODS (section 5.2)

Treatments

The effect of four supplement treatments on the intake and tissue gain of Scottish Blackface lambs grazing either rape leaf (cv Lair) or hybrid turnip (cv. Tyfon) were examined in an experiment with 64 lambs in a 4 x 2 factorial design. The four supplement treatments are summarised below:-

0	No supplement
B	140 g OM day^{-1} pelleted rolled barley
BS	140 g OM day^{-1} pelleted rolled barley (0.75) soya bean meal (0.25)
SBP	140 g OM day^{-1} pelleted dried molassed sugar beet pulp

There were eight lambs per supplement treatment on each crop. The experiment was conducted over 61 days between October and December, 1984 at the Hill Farming Research Organisation's Hartwood Research Station, Shotts, Lanarkshire. The experimental design was not replicated.

Animals

Eighty-four Scottish Blackface wether lambs, aged five months and weighing 24.3 (s.e. = 0.19) kg at the start of the experiment, were used. After weaning in mid-August, the lambs were grazed on a perennial ryegrass/white clover sward until early October. From mid-September, the lambs were group-fed 50 g DM day^{-1} rolled barley to accustom them to consuming supplements.

In early September five lambs from the group were prepared with an oesophageal fistula by the method of Van Dyne and Torell (1964). They were offered fresh chopped perennial ryegrass daily indoors until early October.

All lambs were dosed with 1 g of copper needles in early July. In late August, they received a clostridium/pneumonia vaccine (Heptavac-P, Hoescht) and were dosed with Fenbendazole (Panacur, Hoescht). This latter treatment was repeated six weeks later in early October before the lambs were introduced to the brassica crops. In mid-October 0.75 of the lambs developed contageous pustular dermatitis (Orf). This was treated by daily local application of oxytetracycline hydrochloride for a period of 14 days until visible signs of infection had disappeared.

At the start of the experiment, all 78 lambs were weighed and allocated to one of the eight treatment groups (eight lambs per group) and one initial slaughter group of 14 lambs, such that the means and variation about the means for each group in liveweight were similar.

Experimental Area

An area (1.5 ha) was sown with hybrid turnip (cv. Tyfon) and rape (cv. Lair) on June 4, 1984 at a seed rate of 6.6 kg ha^{-1} with 625 kg ha^{-1} of a 22:11:11 compound fertiliser being applied to the seed-bed. In mid-September the DM yield of each crop was estimated and the area for each crop was divided into three plots of approximately 0.5 ha, such that each plot gave the lambs an initial allowance of leaf of 180 g DM $kg^{-1}W$ day^{-1} which would provide sufficient grazing of leaf over a three week period. As the lambs consume all the lamina and petiole before consuming the stem of the rape plant, they were moved into the next plot of rape when all the petiole had been consumed. The lambs grazing hybrid turnip were moved to the next plot when they had consumed all the leaf material, leaving the bulb intact.

Experimental Procedures

Thirty-two lambs grazed the same plot of each crop together for a period of three weeks before being transferred to a new area on days 22 and 43. At 1000h daily, the lambs were individually penned and offered their supplement treatment. The lambs were given 20 minutes to consume the supplement.

Measurements

Carcase Composition. The 14 lambs in the initial slaughter group were fasted for 24 h prior to slaughter. At slaughter, the fleece, pelt, head, heart, lungs, kidney and associated fat and empty gut, which comprised the non-carcase components (remainder), and the dressed carcase were weighed separately. One half of each carcase was jointed and dissected into bone, fat and muscle tissue and weighed. The non-carcase components and the dissected tissues were then analysed separately for fat, nitrogen and ash contents. The results from the separate components were then summed to give chemical or tissue weights in the whole carcase and in the whole body. Estimates of the initial fat and protein content (kg) of the carcase and whole body of the remaining 64 lambs were obtained by regressing the chemical composition of the initial slaughter group against initial liveweight (W kg). The equations are given below:-

Carcase fat content (kg) = 0.05804W-0.07317 (r = 0.42,RSD=0.2368)

Total fat content (kg) = 0.09219W-0.17025 (r = 0.44,RSD=0.3566)

Carcase protein content(kg) = 0.07465W+0.02629 (r=0.86,RSD=0.0857)

Total protein content(kg) = 0.10402W+0.58361(r = 0.93, RSD=0.797)

On day 61, six lambs per treatment were slaughtered after a 24 h fast and the carcases analysed by the same methods as for the initial slaughter group.

Intake. Intakes of rape leaf were estimated by two methods. In the first method (Method A), intake was estimated from the equation:-

$$\text{OM Intake (g day}^{-1}\text{)} = \frac{\text{Faecal output (gOM day}^{-1}\text{)}}{\text{1-digestibility coefficient}}$$

Faecal output was estimated using the chromic oxide dilution technique. Paper impregnated with chromic oxide was administered to the lambs daily and faeces collected for five days from day 5 of the marker being administered. In the lambs fed supplements, the faecal output was partitioned into that of supplement or crop origin, based on a knowledge of the supplement intake, assuming a digestibility of the supplement of 0.85 (estimated from the data of Experiment 2, Chapter 4) and the absence of any associate effects on total diet digestibility. The digestibility of the rape leaf was predicted from the in vitro digestibility of extrusa samples, obtained from the oesophageal-fistulated lambs.

The second method (Method B) was that based on the n-alkane method described by Mayes et al (1986) and used the equation:-

$$\text{OM Intake (g day}^{-1}\text{)} = \frac{\frac{Fi}{Fj}(Dj+Is.Sj)-IsSi}{Ci - \frac{Fi.Cj}{Fj}}$$

where Ci, Si and Fi are the respective concentrations (mg g^{-1} OM) of the natural alkane (C29) in the OM of rape leaf, supplement and faeces; Cj, Sj and Fj are the respective concentrations (mgg^{-1} OM) of the dosed alkane (C28) in OM of the crop, supplement and faeces; I is the intake of supplement (gOM day^{-1}) and Dj is the daily amount of alkane (C28) dose by pellet (mg). C28-alkane was chosen as the dosed alkane as C29-alkane is the most common naturally occurring alkane in rape leaf and C28-alkane has a similar recovery rate to it.

Measurements of intake of hybrid turnip by lambs were made only by Method A in a similar manner to that for rape leaf.

On day 9 and 30 of the experiment and daily for the subsequent 10 days, after the supplement had been consumed, the lambs were dosed with a pellet (1.75g) of paper impregnated with chromic oxide. In addition, the lambs grazing rape leaf were also dosed with another pellet (1.2g) of paper impregnated with octacosane (C28-alkane). On day 14 and 35 and daily for the subsequent five days, faecal grab samples were taken once daily at the same time as the lambs were dosed. The faeces were frozen and subsequently bulked over each five-day period and analysed for chromium and C28 alkane and the naturally occurring C29-alkane.

During the faecal collection periods, samples of extrusa from 5 oesophageal fistulated lambs were collected from both the rape and hybrid turnip plots being grazed. For at least 24 h before collections the lambs were grazed in similar plots to the experimental animals to become accustomed to the crop. The lambs were starved for 4 h prior to being allowed to graze the experimental plots for approximately 20 minutes until sufficient sample had been collected. The samples were stored at 0°C until frozen at -20°C approximately 30 minutes later. These samples were freeze dried and analysed for <u>in vitro</u> digestibility and in the case of the rape samples for n-alkane content.

All supplements were in a pelleted form and the barley had been rolled before pelleting. The pellet size was approximately 2 cm with a diameter of 1 cm. Individual refusals of supplement were collected and the weight recorded daily. The chemical composition of the supplements is given in Table 5.1.

TABLE 5.1. Chemical composition of supplements offered throughout the experiment

	DM (gkg^{-1})	Ash (gkg^{-1}DM)	N (gkg^{-1}DM)	NDF (gkg^{-1}DM)	ADF (gkg^{-1}DM)	ADL (gkg^{-1}DM)
Barley	851	32	15.5	199	57	7.5
Barley/soya bean meal	878	39	27.3	189	65	6.9
Dried molassed sugar beet pulp	898	85	11.9	392	236	21.8

Herbage Mass. Quadrats (40 x 60 cm, 10 per operator per plot, 2 operators) were cut on day 1 and weekly thereafter until the end of the experiment. Each quadrat was placed randomly on a transect of each plot and the material within the quadrat was divided into standing crop and litter. The standing crop and litter samples were bulked for each operator and sub-sampled for DM determination (oven dried at 80°C for 48h). The remainder of each sample was stored at -20°C and subsequently separated into lamina, petiole, stem or weed in the case of the rape and crop or weed in the case of the hybrid turnip. The separated fractions were then freeze dried and analysed for OM.

Liveweight. Liveweights of the lambs were recorded at weekly intervals throughout the experiment.

Analyses

N, NDF and ADF contents of the extrusa samples and supplements and OM content of the extrusa samples, supplements and quadrats were analysed as described in Section 3.2. Carcase fat, N and ash were estimated using the methods outlined by Russel et al (1968). In vitro digestibility was estimated by the method of Tilley and Terry (1963) as modified by Alexander and McGowan (1966) using rape samples of known in vivo digestibility as standards. Chromium was determined on freeze dried faeces by X-ray fluorescence spectrometry (PW 1212, Phillips, Cambridge) as outlined by Evans et al (1977).

Statistical Analyses

Statistical analyses were performed using the analysis of variance of GENSTAT (release 4.04B, Lawes Agricultural Trust, Rothamsted Experimental Station, 1984). The main effects were crop and supplement type. In addition, with the intake data, the effect of period was taken into account.

RESULTS (Section 5.3)

The weights of standing crop and litter of rape and its composition in all three periods are described in Figure 5.1. As each of the periods progressed, the weight of lamina and petiole components declined, but the stem component remained constant, indicating that the lambs ingested only the leaf and petiole components. The weight of weed in the standing crop declined and entered the litter category such that the weed component comprised an increasing portion of the litter over each period. The weight of standing crop of hybrid turnip (excluding the bulb) and litter in all three periods are described in Figure 5.2. The weight of hybrid turnip at the start of the period was slightly lower (2.7 vs 3.1 t OM ha^{-1}) than the leaf components of the rape crop due to the stem component of the rape crop being less than the predicted proportion of 0.5 of the total weight of standing crop. Unlike the rape crop, the weight of litter did not increase over the period, remaining at around 1400 kg OM ha^{-1}, the weed component comprising approximately 0.5 of the total weight.

The chemical composition of the crop components at the start of Periods 1 and 2 is given in Table 5.2. There was little difference in chemical composition between periods except that the rape stem had a higher and hybrid turnip a slightly lower N content in Period 2 than Period 1. Rape stem and petiole had similar N contents with the lamina components having a higher N content which was similar to that of the hybrid turnip. The NDF and ADF contents of the hybrid turnip were intermediate between those of the rape petiole and lamina.

In vitro digestibility values of extrusa samples from the oesophageal fistulated lambs in Period 1 for rape leaf and hybrid turnip were 0.832 (s.e. = 0.0046) and 0.847 (s.e. = 0.0048) respectively. They were slightly

FIGURE 5.1. Composition of standing crop and litter of rape (t OM ha^{-1}) (combined data from three periods)

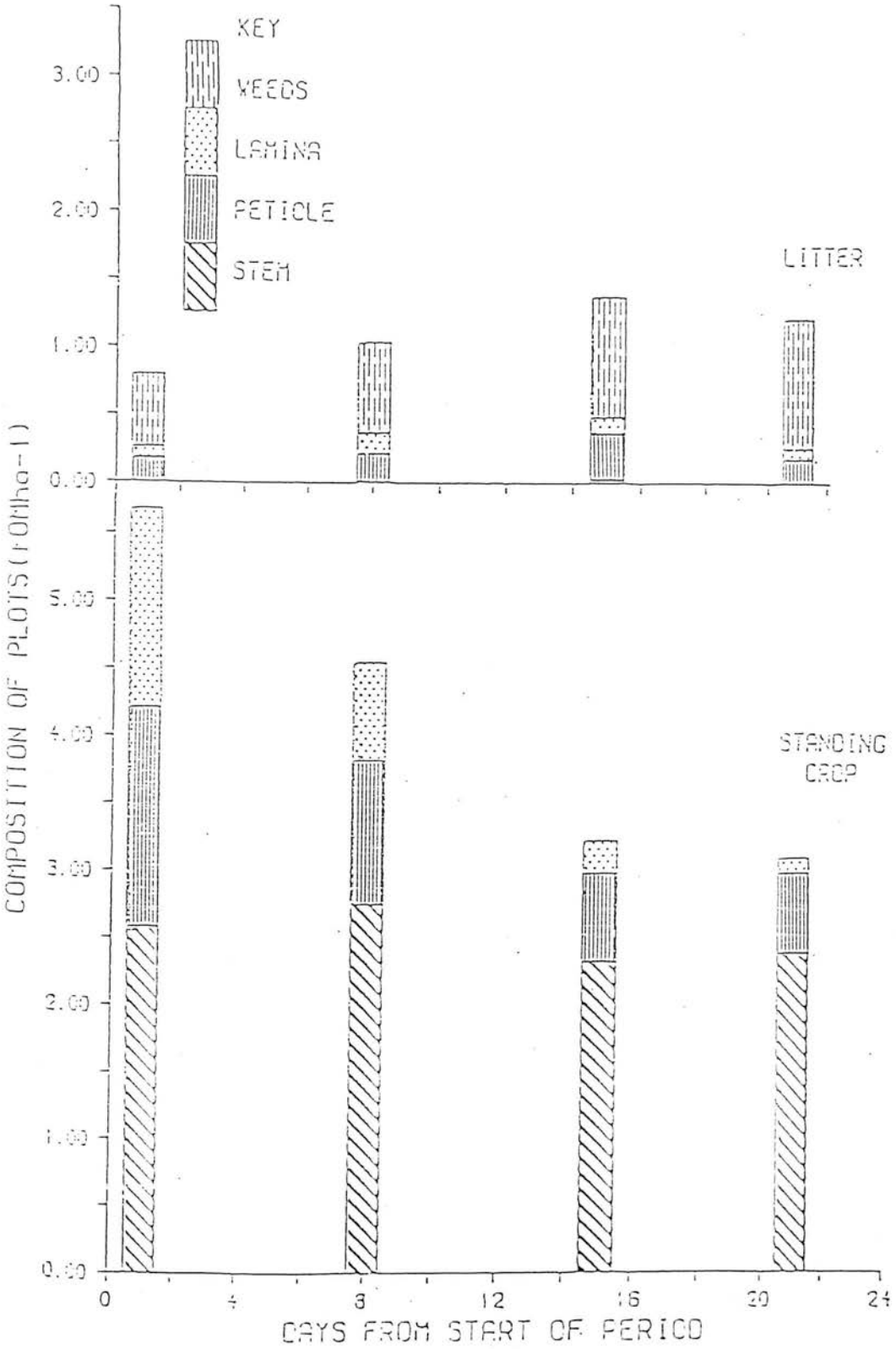


FIGURE 5.2. Composition of standing crop and litter of hybrid turnip (t OM ha^{-1}) (combined data from three periods)

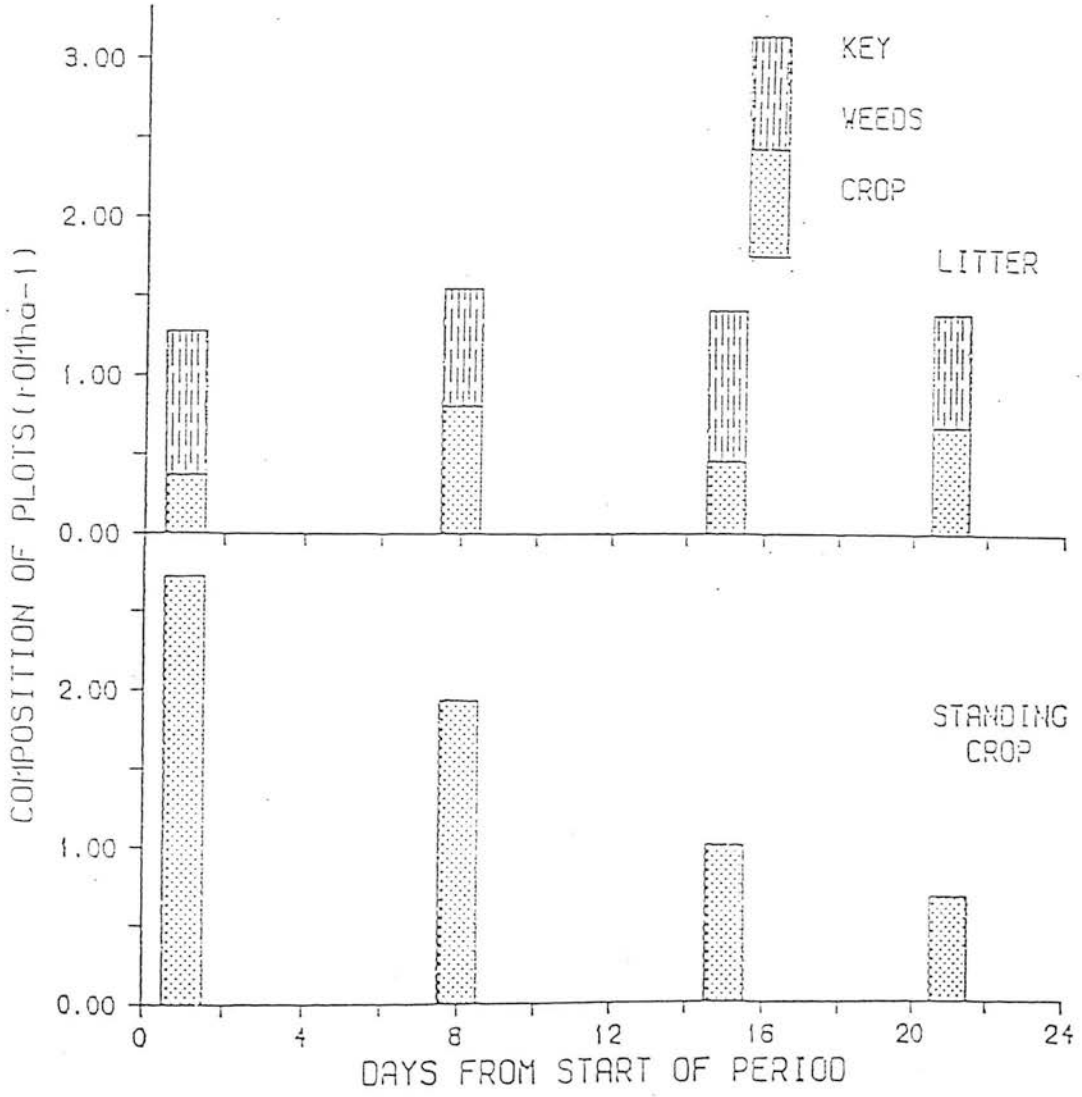


TABLE 5.2. Chemical composition of crop components at the start of periods 1 and 2.

		Ash ($gkg^{-1}DM$)	N ($gkg^{-1}DM$)	NDF ($gkg^{-1}DM$)	ADF ($gkg^{-1}DM$)
Period 1	Rape lamina	129	45.3	151	125
	Rape petiole	146	19.6	243	209
	Rape stem	91	15.9	340	257
	Hybrid turnip	168	41.3	200	169
Period 2	Rape lamina	161	43.8	164	132
	Rape petiole	149	22.1	224	201
	Rape stem	94	24.4	336	258
	Hybrid turnip	171	37.7	207	177

higher but not significantly so in Period 2 (0.851, (s.e. = 0.0022) and 0.862, (s.e. = 0.0048) for rape leaf and hybrid turnip respectively). Intakes of the barley and barley/soya bean meal supplements in period 1 were approximately 0.78 of that offered for lambs grazing both forage crops. In period 2, however, all of these supplements was consumed (See Table 5.3). In contrast, with lambs grazing rape leaf the intake of the dried molassed sugar beet pulp supplement was only 0.17 of amount offered, rising to 0.59 in period 2. With lambs grazing hybrid turnip and offered the same supplement intake of the supplement was zero in period 1 and was only 0.21 of the amount offered in period 2.

There were no significant differences between periods in the intakes of OM of forages estimated using Method A (Table 5.3). However, when expressed per kg liveweight (see Table 5.4), estimates of OM intake of forage were significantly ($P < 0.05$) higher in period 1 than in period 2 (28.4 vs 25.6 g OM $kg^{-1}W$, s.e. = 0.96), reflecting a slight decline in forage intakes in period 2 whilst liveweights increased. Over both periods mean intakes of rape leaf were significantly ($P < 0.05$) higher than those for hybrid turnip (mean OM intakes 845 vs 762 gOM day^{-1}, s.e. = 27.6). This was predominantly due to lower intakes of hybrid turnip in period 2.

There were no significant differences in forage intake between lambs receiving the two supplements containing barley in either period. The low intakes of the dried molassed sugar beet pulp supplement make comparisons meaningless. The substitution rates of forage by the barley/soya bean meal supplement were similar for both periods and for both crops (0.3 to 0.6 g decrease in forage OM intake per g increase in supplement OM intake). However substitution rates with the barley supplement for both crops were very variable, ranging from 0 to 1.6 g

TABLE 5.3. Intake of forage and supplement and digestible OM intake ($gOMday^{-1}$) by lambs grazing two forage brassica and offered one of four supplement treatments during period 1 and 2 (estimated using Method A).

		Supplement				
		No Supplement	140gOM barley	140gOM barley/soya bean meal	140gOM dried molassed sugar beet pulp	s.e.
Period 1	Intake of rape	870	944	816	794	78.1
	Intake of supplement	-	108	110	24	
	Total intake	870	1052	926	818	79.1
	Total digestible OM intake	724	877	772	681	66.8
	Intake of hybrid turnip	844	750	791	807	78.1
	Intake of supplement	-	110	100	0	
	Total intake	844	860	891	807	79.1
	Total digestible OM intake	715	729	755	684	66.8
Period 2	Intake of rape	919	715	821	877	78.1
	Intake of supplement	-	123	137	83	
	Total intake	919	838	958	960	79.1
	Total digestible OM intake	782	713	683	663	66.8
	Intake of hybrid turnip	696	812	657	739	78.1
	Intake of supplement	-	138	137	30	
	Total intake	696	950	794	769	78.1
	Total digestible OM intake	600	817	815	817	66.8
Mean of both periods	Intake of rape	895	830	818	836	55.2
	Intake of supplement	-	115	124	53	
	Total intake	895	945	942	889	55.9
	Total digestible OM intake	753	795	793	749	47.2
	Intake of hybrid turnip	770	781	724	773	55.2
	Intake of supplement	-	124	119	15	
	Total intake	770	905	843	788	55.9
	Total digestible OM intake	657	773	717	673	47.2

TABLE 5.4. Intake of forage and supplement ($gOMkgW^{-1}$) by lambs grazing two forage brassica crops as offered one of four supplement treatments during period 1 and 2 (estimated using Method A).

	Supplement				
	No Supplement	140gOM barley	140gOM barley/soya	140gOM dried molassed sugar beet pulp	s.e.
Period 1					
Intake of rape	30.8	32.0	28.2	26.8	2.73
Intake of supplement	-	3.6	3.7	0.8	-
Total intake	30.8	35.6	31.9	27.6	2.76
Intake of hybrid turnip	28.4	26.2	26.9	28.1	2.73
Intake of supplement	-	3.7	3.4	0	-
Total intake	28.4	29.9	30.3	28.1	2.76
Period 2					
Intake of rape	31.1	22.6	26.3	27.4	2.73
Intake of supplement	-	3.9	4.3	2.6	-
Total intake	31.1	26.5	30.6	30.0	2.76
Intake of hybrid turnip	23.2	27.3	22.2	25.0	2.73
Intake of supplement	-	4.6	4.7	1.0	-
Total intake	23.2	31.9	26.9	26.0	2.76
Mean of both periods					
Intake of rape	31.0	27.3	27.2	27.1	1.93
Intake of supplement	-	3.8	4.1	1.7	-
Total intake	31.0	31.1	31.3	28.8	1.95
Intake of hybrid turnip	25.8	26.7	24.5	26.5	1.93
Intake of supplement	-	4.2	4.1	0.5	-
Total intake	25.8	30.9	28.6	27.0	1.95

decrease in forage OM intake per g increase in supplement OM intake.

Total digestible OM intakes showed similar trends to that of the OM intake data.

The estimates of OM intake of rape leaf and total OM intake using Method B are given in Table 5.5. There were no significant differences between the barley supplement treatments nor between periods. Mean substitution rates were 0.4 and 0 g decrease in forage intake per g of supplement intake for the B and BS treatments respectively. Compared to the estimates of intake using Method A, estimates of intake using this method were 0.15 higher, although the means conceal considerable variation.

The changes in liveweight during the experiment are illustrated in Figure 5.3. There was no significant differences between treatments within a crop and therefore the mean liveweights for each crop are given. After approximately 20 days of grazing the crop, liveweight gains of lambs grazing rape were higher than those of lambs grazing hybrid turnip. At slaughter, the liveweights of lambs grazing rape were significantly ($P < 0.05$) higher than those of lambs grazing hybrid turnip (37.4 vs 34.8 kg, s.e. = 0.374). However, the difference between the crops in carcase weight (Table 5.6) just failed to reach statistical significance ($P = 0.06$) (17.1 vs 16.3, s.e. = 0.30).

The weights of muscle and fat in the carcase at slaughter and the amounts of crude protein and chemical fat in the carcase are given in Tables 5.6 and 5.7 respectively. There were no significant differences between the two crops across all treatments in the weight of muscle or the amounts of crude protein in the carcase, but the amounts of carcase fat and chemical fat were significantly ($P < 0.05$) higher in the lambs grazing rape compared to hybrid turnip (carcase fat 4.94 vs 4.32 kg, s.e.

TABLE 5.5. Intake of rape leaf and total intake (gOM day^{-1}) by lambs offered one of four supplement treatments during periods 1 and 2 (estimated using Method B).

	Supplement				
	No supplement	140 gOM barley	140gOM barley/ soya bean meal	140gOM dried molassed sugar beet pulp	s.e.
Period 1					
Intake of rape	986	936	987	904	80.0
Total intake	986	1043	1097	927	78.5
Period 2					
Intake of rape	1040	990	1032	1165	80.0
Total intake	1040	1113	1169	1247	78.5
Mean of both periods					
Intake of rape	1013	963	1009	1034	56.6
Total intake	1013	1078	1135	1087	55.5

FIGURE 5.3. Liveweight (kg) of lambs grazing either rape or hybrid turnip over experiment (combined supplement treatments)

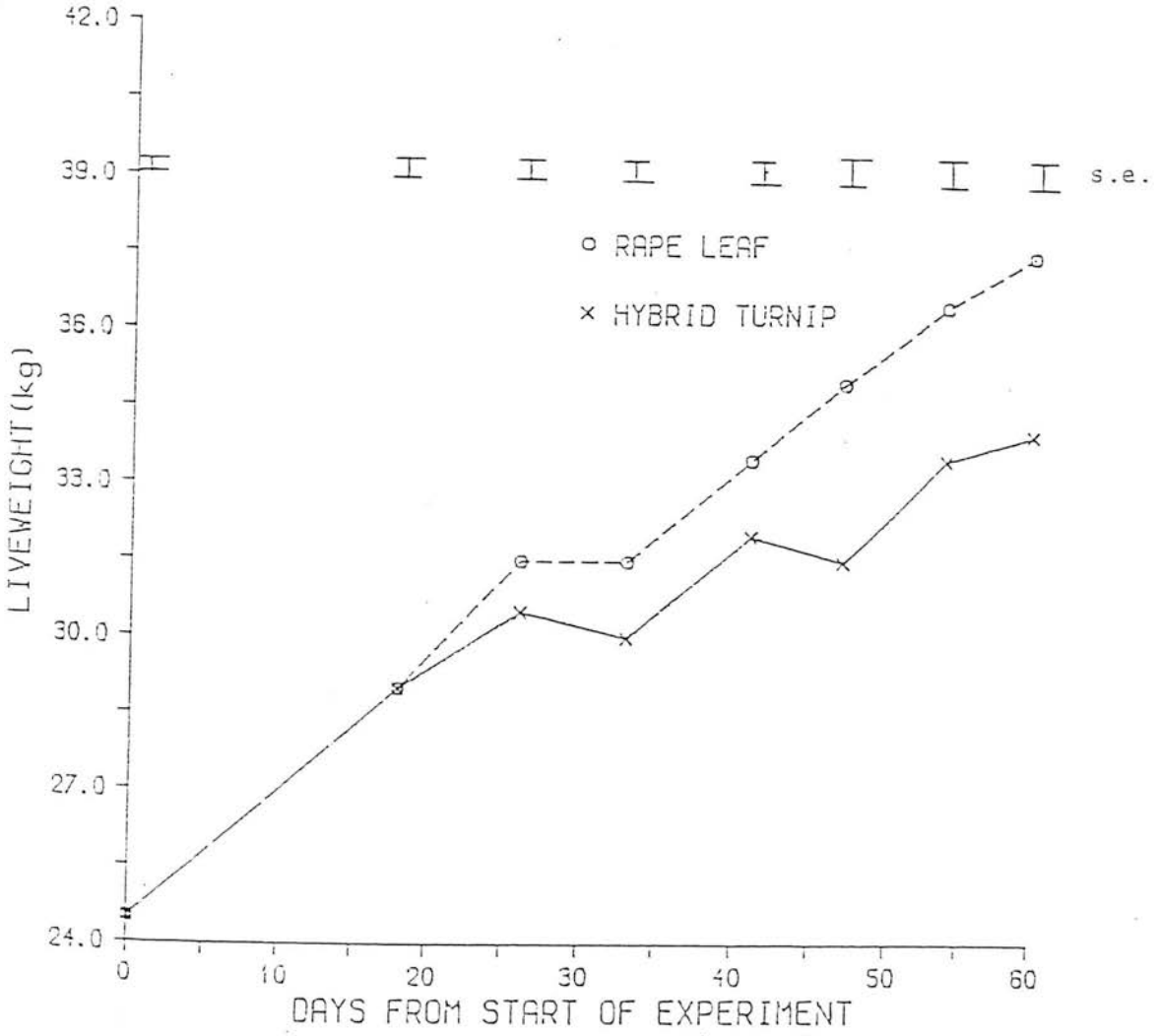


TABLE 5.6. Carcase weight and weight of muscle and fat in carcase (kg) at slaughter in lambs grazing two forage brassica crops and offered one of four supplement treatments.

	Supplement				
	No supplement	140gOM barley	140gOM barley/ soya bean meal	140gOM dried molassed sugar beet pulp	s.e.
Carcase weight (kg)					
Rape	16.9	17.0	16.9	17.6	0.60
Hybrid turnip	15.8	16.5	16.8	15.8	
Weight of muscle (kg)					
Rape	8.33	7.99	7.83	8.41	0.280
Hybrid turnip	8.11	8.53	9.26	9.91	
Weight of fat (kg)					
Rape	4.82	5.04	4.86	5.05	0.388
Hybrid turnip	3.98	4.29	4.58	4.44	

TABLE 5.7. Weight of carcase crude protein and chemical fat at slaughter expressed in kg and per kg carcase weight in lambs grazing two forage brassica crops and offered one of four supplement treatments.

	Supplement				
	No supplement	140gOM barley	140gOM barley/soya bean meal	140gOM dried molassed sugar beet pulp	s.e.
Crude protein in carcase (kg)					
Rape	2.72	2.66	2.61	2.79	0.093
Hybrid turnip	2.45	2.72	2.76	2.48	
Chemical fat in carcase (kg)					
Rape	3.82	3.84	4.01	4.01	0.344
Hybrid turnip	3.08	3.43	3.54	3.48	
Crude protein per unit carcase weight					
Rape	0.162	0.157	0.155	0.159	0.0045
Hybrid turnip	0.155	0.165	0.164	0.157	
Chemical fat per unit carcase weight					
Rape	0.222	0.224	0.236	0.227	0.0141
Hybrid turnip	0.193	0.207	0.208	0.217	

= 0.194; chemical fat in carcase 3.92 vs 3.38 kg, s.e. = 0.172). There was a significant ($P < 0.05$) crop x supplement interaction associated with the weight of muscle at slaughter and the amount of crude protein in the carcase. This was predominantly due to the higher amounts of muscle or crude protein present in the carcase of lambs on the rape leaf treatments whilst that of lambs grazing the unsupplemented hybrid turnip were lower than that of lambs grazing the supplemented hybrid turnip. When expressed as a proportion of carcase weight, these crop x supplement interactions disappeared. The proportion of chemical fat in the carcase in lambs grazing rape was significantly higher ($P < 0.05$) than in the carcase of lambs grazing hybrid turnip (0.228 vs 0.206, s.e. = 0.0071).

There were no significant differences between crops or crop supplement interactions in the amount of crude protein in the whole body (Table 5.8). However, as with the carcase data, lambs grazing rape leaf had significantly higher ($P < 0.01$) amounts of chemical fat in the whole body than lambs grazing hybrid turnip (5.97 vs 5.11 kg, s.e. = 0.227). These differences were also evident when the data were expressed as a proportion of empty body weight at slaughter (crude protein 0.173 vs 0.172, s.e. = 0.0017; chemical fat 0.231 vs 0.203, s.e. = 0.0064).

The gains in carcase crude protein and chemical fat and the carcase and total energy gains are presented in Table 5.9. As with the amount of crude protein in the carcase at slaughter, there was a significant crop supplement interaction for the crude protein gains. The same differences in fat content were also evident and accounted for the significantly higher ($P < 0.05$) carcase and total energy gains with lambs grazing rape leaf compared to hybrid turnip (carcase energy gain 2.25 vs

TABLE 5.8. Weight of whole body crude protein and chemical fat at slaughter expressed in kg and per kg empty body weight in lambs grazing two forage brassica crops and offered one of four supplement treatments.

	Supplement				
	No supplement	140gOM barley	140gOM barley/soya bean meal	140gOM dried molassed sugar beet pulp	s.e.
Crude protein in whole body (kg)					
Rape	4.36	4.26	4.35	4.54	0.130
Hybrid turnip	4.14	4.29	4.46	4.15	
Chemical fat in whole body (kg)					
Rape	6.03	5.79	6.09	5.96	0.455
Hybrid turnip	4.72	5.09	5.31	5.31	
Crude protein per unit empty body weight					
Rape	0.170	0.173	0.173	0.175	0.0034
Hybrid turnip	0.170	0.174	0.170	0.173	
Chemical fat per unit empty body weight					
Rape	0.232	0.225	0.241	0.228	0.0128
Hybrid turnip	0.193	0.200	0.201	0.218	

TABLE 5.9. Gains in carcase crude protein and chemical fat ($gday^{-1}$) and gains in carcase and whole body energy ($MJday^{-1}$) in lambs grazing two forage brassica crops and offered one of four supplement treatments.

	Supplement				
	No supplement	140gOM barley	140gOM barley/soya bean meal	140gOM dried molassed sugar beet pulp	s.e.
Crude protein gains in carcase ($gday^{-1}$)					
Rape	16.2	15.0	13.4	17.4	1.59
Hybrid turnip	10.1	16.6	17.1	11.0	
Chemical fat gains in carcase ($gday^{-1}$)					
Rape	46.1	46.5	49.5	49.6	6.37
Hybrid turnip	32.3	38.9	41.0	39.7	
Energy gains in carcase ($MJday^{-1}$)					
Rape	2.19	2.18	2.27	2.36	0.259
Hybrid turnip	1.51	1.92	2.01	1.82	
Energy gains in whole body ($MJday^{-1}$)					
Rape	3.43	3.28	3.48	3.46	0.342
Hybrid turnip	2.34	2.79	2.95	2.97	

1.82 MJ day^{-1}, s.e. = 0.129; total energy gains 3.41 vs 2.72 MJ day^{-1}, s.e. = 0.171).

The data for individual animals used to derive all the means in this experiment is given in Appendix Tables 5.1, 5.2 and 5.3.

DISCUSSION (section 5.4)

The principal objective of this experiment was to test the hypothesis, set up in Experiment 1 (Chapter 3), that tissue gains in lambs grazing rape leaf or hybrid turnip were limited by the supply of energy substrates and that supplementation with an energy-based supplement would increase tissue gains depending upon the substitution rate of the intake of forage by that of the supplement. The intention was also to compare the form in which the energy in the supplement was provided. However the mean intake of the dried molassed sugar beet pulp supplement over the experiment was only 59 g OM day^{-1} and most of this was consumed in the last two weeks of the experiment (i.e. after period 2). Consequently no attempt is made to interpret the results for the SBP treatment. The lambs given the barley and barley/soya bean meal supplements consumed most of their supplement from week 3 of the experiment.

A comparison between the two methods of estimating the intake of rape leaf highlights the difficulties in measuring the intakes of lambs grazing forage brassicas. Method A involved estimating faecal output and predicting the indigestibility of the diet from extrusa samples derived from oesophageal-fistulated animals. This method has been the most widely used in grazing studies in the last ten years and has been used previously for forage brassica intake measurements (Armstrong et al, 1984). The main potential bias in this method occurs in the measurement of digesitibility. Tilley and Terry (1963) found a linear

relationship between in vitro and in vivo DM digestibility at a maintenance level of feeding but only tested samples up to a DM digestibility of 0.83 which is at the lower end of the range measured in Experiment 1 (0.82 to 0.85). However Armstrong (unpublished data) using forage brassicas also found a linear relationship between in vivo DM digestibility, determined at voluntary intake and in vitro DM digestibility up to a DM digestibility of 0.900. This gives some confidence that the in vitro digestibilities in this experiment gave a true representation of the in vivo digestibility in this experiment.

Moreover in vitro digestibility values of the rape leaf were within 0.02 units to that of the in vivo digestibility values for the rape leaf fraction obtained in Experiment 2 (0.842 vs 0.867) from the same experimental material. However such a 0.02 difference in digestibility can lead to a 0.15 difference in estimated intake and therefore could lead to a bias in the estimates of intake using Method A.

In addition to possible errors in estimating forage digestibility, there are also possible errors associated with partitioning the faecal output between supplement and forage origin. Assumptions about the digestibility of the supplements were made based on the data derived from Experiment 2 where no significant difference between the apparent digestibility of OM of the unsupplemented and the barley supplementation treatment was observed. It was thus assumed that there were no associative effects of the supplement on forage digestibility and a value for the digestibility of OM of the supplement was derived. As the BS and SBP treatments were not used in Experiment 2, the assumptions that they had similar OM digestibilities to that of the B treatment and that no associative effects existed was not tested.

Method B relies on measuring the relative concentrations of dosed

and naturally occurring alkanes in the forage ingested, in the supplement and in the faeces to estimate intake and therefore does not include the errors involved in estimating in vitro digestibility. It has been used successfully to measure the herbage intakes of sheep grazing perennial ryegrass swards and when given supplements (e.g. Milne et al, 1986) and also to identify the herbage intakes of sheep grazing swards of different plant species (e.g. Milne and Grant, 1988). The major possibility for error associated with this method with forage brassicas is that the composition of the extrusa samples from oesophageal fistulated lambs may not have been identical to the actual diet consumed by the lambs in which the faecal alkane concentrations were determined. With both methods used in this experiment, it has been assumed that the extrusa samples collected from the oesophageal fistulated lambs were identical to that consumed by the rest of the lambs in the experiment. This is more important for the alkane measurement in the case of forage brassicas where not only can lambs be more selective than when grazing pasture (Armstrong, R.H. pers. comm.) but also because of the large difference in C29 alkane concentration between lamina (5786 mg kg^{-1} DM) and petiole (954 mg kg^{-1} DM) (Mayes, R.W. pers. comm.). Altering the proportions of lamina and petiole in the extrusa has a large effect on intake such that a slight change in the proportion of lamina in the extrusa from 0.5 to 0.45 or 0.55 would result in forage brassica intake varying by 0.15.

It is not possible to conclude which of the two methods of estimating intake are likely to have produced the greater errors or biases. Because of the differences between intakes of forage brassicas within treatment A using the two methods it is difficult to draw firm conclusions about substitution rates. The substitution rates were less

variable for rape leaf using Method B with mean values of 0.4 and 0 for the B and BS treatments respectively indicating a relatively low substitution rate for rape leaf. As they are broadly similar to the values of 0 and 0.4 for the B and BS treatments respectively with lambs grazing hybrid turnip and derived from intakes estimated using Method A, it may be concluded that there are no large differences between the two forages in substitution rate.

The estimates of intake using both methods indicated that lambs grazing rape leaf have higher intakes than those grazing hybrid turnip. A possible explanation for this difference between the two crops lies in the difference in herbage allowance. Prior to the start of the experiment, the yield of both crops was estimated. Plots were fenced off to provide equal allowances of rape leaf and hybrid turnip, assuming that the leaf component of the rape crop comprised 0.50 of the weight of the crop. However, as a consequence of the leaf component of rape crop comprising 0.55 of the total yield at the start of the experiment, the rape plot contained 3.1 t OM ha^{-1} rape leaf compared to 2.7 t OM ha^{-1} in the hybrid turnip plot. This, together with the higher wastage of the hybrid turnip crop (as seen by the greater proportion of hybrid turnip in the litter category (mean over period = 0.58 t OM ha^{-1}) compared to the rape leaf litter (0.32 t OM ha^{-1})) led to a higher allowance of leaf offered to lambs grazing the rape crop compared to those grazing hybrid turnip. As it has been observed that level of allowance may affect forage intake (Barry et al, 1981a) and liveweight gain (Young et al, 1982), this may account for the higher intakes and liveweight gains observed in this study with lambs grazing rape leaf.

The differences between the two crops in carcase weight at slaughter reflected the differences in intake. When supplemented, the

additional nutrient supply with lambs grazing rape leaf was apparently partitioned into fat with no increase in protein tissue (Table 5.7 and 5.8). The failure of this increased nutrient supply to result in significantly higher carcase weights with lambs grazing rape leaf is probably a reflection of the higher energy requirements to lay down fat than protein, the energy value of chemical fat being 39.3 kJ g^{-1} compared to 23.6 kJ g^{-1} for crude protein (ARC, 1980).

However the effect of the B and BS supplements with hybrid turnip was to significantly ($P < 0.05$) increase the weight of carcase crude protein to a similar or slightly higher level than that found in lambs grazing rape leaf. This was not associated with significant increases in the weight of chemical fat in the carcase. The same trends were apparent with the whole body crude protein data but due to the higher standard errors, they did not reach statistical significance. It is not possible to conclude whether the increased carcase protein gains in lambs grazing hybrid turnip and supplemented were a result of additional energy or N supply. The B treatment was associated with an increase in the DOM intake of 116 g day^{-1}. However it was also associated with an increase in N intake of 2.3 g day^{-1}. The lambs on the BS treatment had lower intakes of forage brassica than on the B treatment, resulting in a smaller increase in DOM intake (60 g day^{-1}) with supplementation compared to the unsupplemented treatment group and similar total N intakes to the B treatment group (32.7 and 31.8 for the B and BS treatment groups respectively). There was no difference between the supplement treatment groups in the ratio of total DOM to N intake making it impossible to conclude if the supplementation with energy or N was responsible for the crude protein gains or was a consequence of higher total intakes. There appeared to be no effects of supple-

mentation on carcase chemical fat or crude protein weights in lambs grazing rape leaf.

The results with the lambs grazing rape leaf are more conclusive however. Total DOM intakes were only slightly increased (40 g day^{-1}) in both the B and BS treatment groups with supplementation, which was probably insufficient to have any significant effect on tissue gain. However the BS treatment increased the N content of the total diet compared to the B treatment (20.2 vs 18.8 g N day^{-1}) and this resulted in no significant increase in tissue gains. This suggests, therefore, that in lambs grazing rape leaf tissue gains are not limited by N substrate and is in agreement with the hypothesis developed on the basis of the results described in Experiment 1 (Chapter 3).

The significantly higher ($P < 0.05$) amounts of fat deposited in both the whole body and carcase of the lambs grazing rape leaf compared to hybrid turnip cannot be totally explained either in terms of a greater carcase weight or because of the difference in the ratio of crude protein to ME with rape leaf and hybrid turnip. The same differences were apparent when whole body and carcase fat weights were expressed as a proportion of final carcase weight and empty body weight (Table 5.7 and 5.8) and were found irrespective of supplement treatment group. The difference between the two forages in the way they influence tissue deposition cannot be explained by the ratio of NAN flow at the abomasum to ME intakes being higher in lambs grazing rape leaf than hybrid turnip. The data from Experiment 2 (Chapter 4), which used the same forages as in this experiment, can be used to estimate this ratio, assuming ME intake is 15.83 x digestible OM intake (Beever et al, 1986). The ratios of 0.58 and 0.56 MJ ME per g NAN flowing at the abomasum for rape leaf and hybrid turnip respectively are very similar.

Carcase gains of energy and protein in this experiment were higher than previously reported (e.g. Fitzgerald, 1984; Armstrong et al, 1984) and is a function of the higher intakes reported in this experiment. The intakes, which are as high as any reported in the literature are probably the result of a variety of factors such as the very favourable weather conditions experienced during the experiment and also the high allowance offered to lambs, particularly with the rape leaf. As discussed in the review of literature (Chapter 2) lamb performance on forage brassicas is very variable and the high carcase gains in this experiment highlight this variation. The experiment has also shown that supplementation may be beneficial in achieving higher carcase gains from hybrid turnip although it has not been possible to determine if this is due to increased energy or nitrogen substrate or a result of increased intake. The factors affecting the partitioning of absorbed nutrients between fat and protein deposition which is apparently different with the two forages also requires further examination.

CHAPTER 6 - EXPERIMENT 4

THE EFFECT OF SUPPLEMENTS ON THE INTAKE BY LAMBS OF RAPE STEM

INTRODUCTION (Section 6.1)

The results from Experiment 1 suggested that microbial protein production and tissue gains in lambs offered stem components were limited by the supply of energy substrates. It was suggested that these would be increased by a cereal or sugar beet pulp supplement. A cereal/protein supplement would indicate any benefit of additional nitrogen supplement in increasing microbial protein production. However, as was pointed out in Chapter 2, there has been, in general, poor responses to supplementation of forage brassicas, probably due to high substitution rates. The objective of this experiment was, therefore, to measure intake and substitution rates of lambs offered a variety of supplements in order to quantify the effect on substitution rate.

MATERIALS AND METHODS (Sectioon 6.2)

Treatments

The effect of four treatments on the intake of Scottish Blackface lambs grazing rape stem were examined with 32 lambs. The four supplement treatments were

0 No supplement

B 140 g OM day^{-1} pelleted rolled barley

BS 140 g OM day^{-1} pelleted rolled barley (0.75)/soya bean meal (0.25)

SBPS 140 g OM day^{-1} pelleted dried molassed sugar beet pulp (0.75)/soya bean meal (0.25)

The experiment was conducted during November, 1984 at the Hill Farming Research Organisation's Hartwood Research Station, Shotts, Lanarkshire.

Animals and Experimental Plots

The animals used in this experiment were treated in exactly the same manner prior to the start of the experiment as those in Experiment 4 (Section 5.2) except that they were grazed at pasture for three weeks longer. The stem crop of rape was that made available from Experiment 5 after the lambs had consumed the lamina and petiole, leaving the stem component. The lambs were introduced to the plots after the lambs in Experiment 3 had been removed. They remained on the plot for 21 days before moving to the next plot. Supplements were offered at the same time and in the same manner as described in Experiment 3.

Measurements

Intake was measured only once when the lambs were in the second plot and was estimated using Method A, as described in section 5.2. Herbage mass and litter was estimated on day 1 and weekly thereafter until the end of the experiment (day 42) by the same methods as used in Experiment 3. Liveweights were measured on day 3 and weekly thereafter until the end of the experiment. On day 15 of the experiment samples of extrusa was collected and analysed for in vitro digestibility by the same method as described in section 5.2. The chemical composition of the supplements and rape stem at the start of the period is given in Table 6.1.

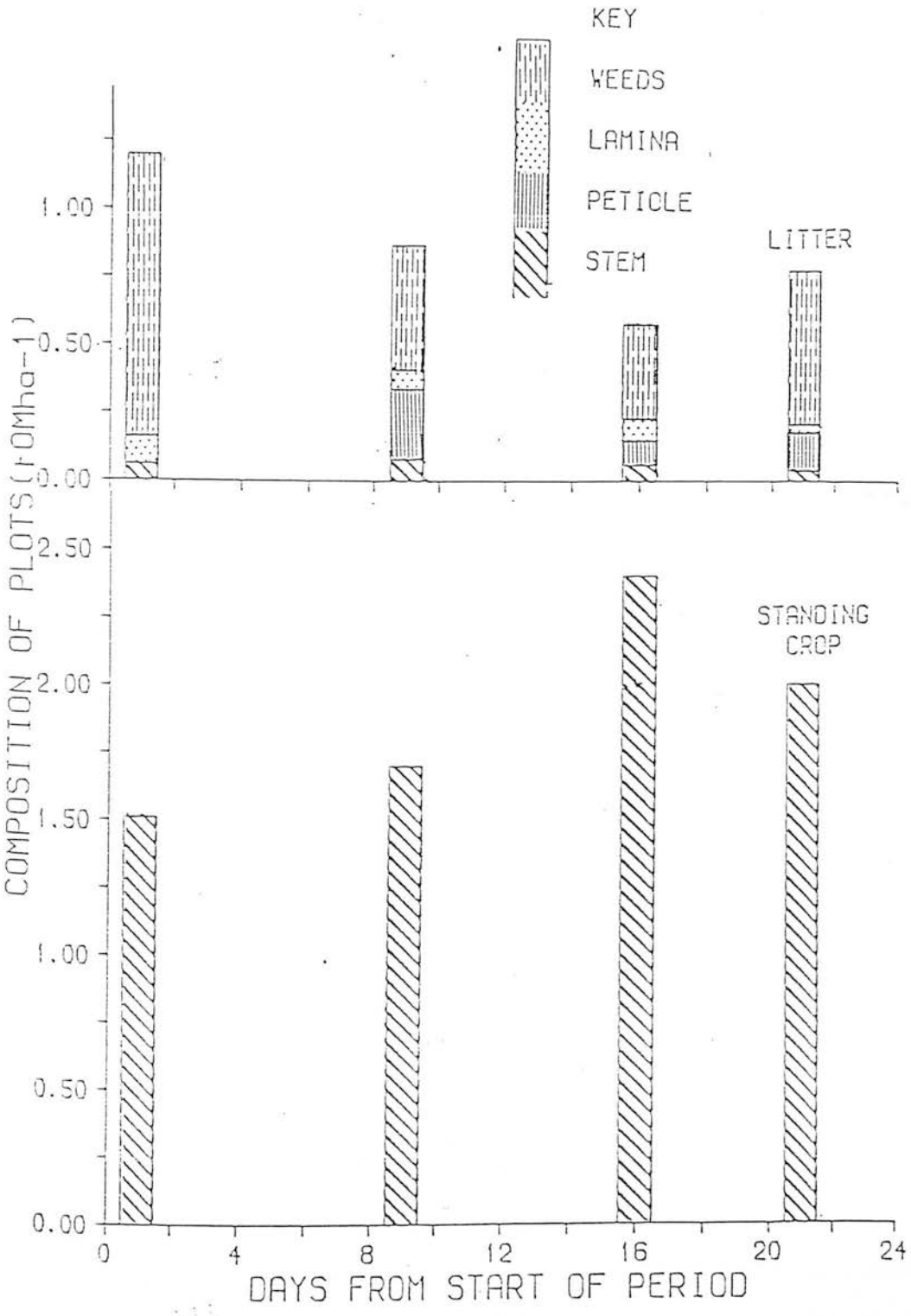
RESULTS (Section 6.3)

The standing crop of rape stem and the composition of the litter over the second period when intakes were estimated is described in Figure 6.1. There was no apparent decline in the amount of rape stem on offer over the experimental period and the composition of the litter remained broadly the same. The in vitro digestibility value of the rape stem extrusa was 0.875 (s.e. 0.0049).

TABLE 6.1. Chemical composition of supplements and rape stem at the start of intake period

	DM (g/kg)	Ash (gkg^{-1} DM)	N (gkg^{-1} DM)	NDF (gkg^{-1} DM)	ADF (gkg^{-1} DM)	ADL (gkg^{-1} DM)
Supplement						
barley	884	32	14.6	170	49	6.3
barley/soya	882	38	31.6	183	68	7.3
sugar beet/ soya	879	91	35.9	401	236	21.5
Crop component		96		512	399	

FIGURE 6.1. Composition of standing crop and litter of rape (t OM ha^{-1}) over period



The mean liveweight gain over the experiment was 141 (s.e. 25.4) g day^{-1} and there were no significant differences between supplement treatments.

The estimates of crop, supplement and total (crop plus supplement) intake are given in Table 6.2. All the supplements were consumed from day 1 of the experiment. There were no significant differences ($P < 0.05$) between the supplement treatments in either the crop or total intake measurements although the estimated substitution rate of the rape stem by the B and BS treatments was only 0.1 to 0.4 g OM g^{-1} supplement intake.

The data for individual animals used to derive all the means in this experiment is given in Appendix Table 6.1.

DISCUSSION (Section 6.4)

The objective of this experiment was to obtain estimates of the intake of rape stem by grazing lambs and when offered a range of supplement treatments to answer similar questions to those posed in Experiment 3. However, the lack of precision in estimating mean intakes was such that it was not possible to estimate what the substitution rates of rape stem by different supplements were. Furthermore, the method used for estimating intakes when supplements were offered may have caused biases. There was no information from indoor experiments, as there was in Experiment 3, to indicate the likelihood of associative effects of the supplements and rape stem and overall diet digestibility. In consequence, the primary objective of the experiment was not achieved.

The high allowance of rape stem (74 g OM kg^{-1} W day^{-1}) throughout the experiment would indicate that the intake of unsupplemented rape stem should be at a near maximum. In comparison with the results of Dove et al (unpublished data) this is indeed the case.

TABLE 6.2. OM intake of rape stem, supplement and total intake (g OM $kg^{-1}W$) by lambs offered one of four supplement treatments.

	Supplement				
	No supplement	140 g OM barley	140 g OM barley/soya bean mean	140 g OM dried molassed sugar beet pulp/soya bean meal	s.e.
Rape stem	22.8	21.0	22.3	18.0	1.66
Supplement	-	4.8	4.6	4.1	-
Total	22.8	25.8	26.9	22.1	1.74

They reported OM intakes of 1.8 g OM kg^{-1} W which are lower than the intakes (2.2 g kg^{-1} W) reported in this experiment. The in vitro digestibility of the extrusa samples in the experiment of Dove et al (unpublished data) were also higher (0.881) than those obtained in this experiment. However, whilst the lambs grazing the plots were observed to consume most of the stem, leaving approximately the bottom 15-20 cm of each stem, the oesophageal fistulated lambs, due perhaps to their lack of experience of grazing rape stem, were observed to consume only the very top of the stem. Armstrong (1984) found that the OM digestibility of the upper stem was significantly higher ($P < 0.001$) than that of the lower stem (0.86 vs 0.77 s.e. = 0.007) and therefore the in vitro digestibility of the extrusa samples may have overestimated the digestibility of the diet of the lambs being used for the intake measurements, leading to an overestimate of intake. Evidence in support of these observations is that similar liveweight gains were obtained in this experiment and that reported by Dove et al (unpublished data) at similar crop allowances.

CHAPTER 7 - EXPERIMENT 5

THE EFFECT ON VOLUNTARY INTAKE OF REDUCING FOAM CONTENT IN THE RUMEN OF LAMBS OFFERED RAPE

INTRODUCTION (Section 7.1)

In the discussion of Experiment 1, several factors were highlighted that may be involved in limiting voluntary intake of lambs offered forage brassicas. One of these factors was the presence of foam. Large quantities of foam were observed to be present in the rumen of lambs offered forage brassicas in both Experiments 1 and 2. In Experiment 1 the hypothesis was put forward that the foam formed could be due to a lack of tactile stimuli on the rumen wall or as a consequence of the small quantities of structural carbohydrate present. The foam caused an increase in the distension of the rumen and thus limited the voluntary intake of forage brassicas.

The objective of this experiment, therefore, was to test these hypotheses by using a commercially available surfactant as an anti-foaming agent and by increasing the amount of tactile stimuli in the rumen by adding pan-scourers to the rumen. These were administered to lambs offered a forage brassica diet and measurements of voluntary intake were made.

MATERIALS AND METHODS (Section 7.2)

The effects of a surfactant or of the presence of a tactile stimuli on the rumen wall on the voluntary intake by 30 Scottish Blackface lambs offered rape (cv. Lair) were measured over a period of 30 days using a randomised block design. The treatments were as follows:-

A - Rape offered *ad libitum*

B - Rape offered *ad libitum* and a twice daily dose of 20mg $kg^{-1}W$ surfactant.

C - Rape offered ad libitum and insertion of six modified pan scourers into the rumen on day 1 of the experiment.

The experiment was conducted during November and December, 1985 at the Hill Farming Research Organisation's Hartwood Research Station, Shotts, Lanarkshire.

Animals

Thirty Scottish Blackface wether lambs, aged 5 months and weighing 30.6 (s.e. = 0.46)kg at the start of the experiment, were obtained from the Hill Farming Research Organisation's Sourhope Research Station, Yetholm, Roxburgh, in early August. Eighteen of the lambs (Group A) were grazed at pasture until early November. The remaining 12 animals (Group B) were housed in late August and each prepared with a rumen cannula (4 cm), as described in Experiment 1 (section 3.2). These lambs were then used in the first part of Experiment 6 until early November. The Group A lambs were brought indoors in early November and housed in individual pens.

In a pre-experimental period of a week all the lambs were offered whole rape at 0.20 in excess of the previous day's intake to establish levels of voluntary intake. The lambs were then blocked into groups of three according to voluntary intake and randomly allocated a treatment within each block. The Group B lambs were confined in metabolism crates for the duration of the experiment. These lambs were also blocked according to voluntary intake and allocated to treatments in the same manner as the Group A lambs.

All lambs were dosed with 1 g copper needles in early July. In early September, all lambs received a clostridium/pneumonia vaccination (Heptavac-P, Hoescht) and were dosed with Fenbendazole (Panacur,

Hoescht). This was repeated six weeks later in mid-October.

Feed

An area (1.0 ha) was sown with rape (cv. Lair) on July 13, 1985 at a seed rate of 7.00 $kgha^{-1}$ with 562$kgha^{-1}$ of a 22:11:11 compound fertilizer being applied to the seed bed. As a result of the exceedingly wet weather during the summer months, the rape crop was very immature and measured only 30 cm in height in November. The entire rape plot was therefore harvested. The rape, which was obtained daily, was cut to ground level using secateurs. Prior to feeding, the rape was chopped into approximately 4 cm lengths using a chaff cutter. A sample was taken daily for DM determination (oven dried at 80°C for 24h). Further samples were bulked over periods of 5 days, subsampled, stored at -20°C, freeze dried, ground and analysed for OM, N, NDF, ADF, ADL, SMCO and total glucosinolate content. The rape was offered in 2 meals at 1200h and 1700h, at 0.20 in excess of the previous day's intake. The refusals were collected at 1130h and analysed for DM and OM content.

Treatment Imposition

The six lambs in Group A allocated to Treatment B, were dosed daily at 0800h and 1630h with 20$mgkg^{-1}W$ of a surfactant (Bloat Guard, Mill Feed Services, Kirriemuir) which contained 530gkg^{-1} w/w of poloxalene. The surfactant was administered orally in gelatine capsules with a nominal volume of 2 ml (Agar Aids, Stansted). The six lambs in Group A allocated to treatment C were dosed on day 1 with six pan scourers (Nyleska products, Cleckheaton). These had been modified to reduce the size to one third of their normal size. The pan scourers were then rolled up in tissue paper and coated in vegetable oil to aid swallowing and given orally.

The Group B lambs were given exactly the same treatment as the Group A lambs except that both the surfactant and the pan scourers were inserted into the rumen via the cannula.

Measurements and Analyses

Voluntary intake was measured on all sheep over the 30 day period. In addition, the Group B lambs were used to assess the volume of liquid in the rumen, liquid outflow rate from the rumen and the quantity of foam present in the rumen. On days 2,9,16,23 and 30, a single dose of 20μG ^{51}Chromium-EDTA was inserted into the rumen at 0800h, the exact time being noted. At approximately 0900h, 1000h, 1200h, 1400h, 1700h, 2000h and 0900h, the exact time being recorded, 20ml of rumen liquor were withdrawn from several areas of the rumen, using a rumen sampler of the same design as used in Experiment 1 (section 3.2). These samples were frozen at -20°C and subsequently counted for ^{51}Chromium by the same method as described in section 3.2 to allow estimates of rumen volume and liquid outflow rates from the rumen to be estimated.

On day 4, 11, 18, 25 and 31, estimates of the foam content in the rumen were made. At 1200h the quantity of rumen contents that was released in 60 seconds when the rumen cannula plug was withdrawn was collected. The quantity was weighed and later separated on a fresh weight basis, into liquid and particulate matter fractions by centrifuging at 3000 r.p.m. for 15 minutes.

The voluntary intake data was divided into sub-periods of 5 days and statistical analysis was performed on the mean intake within this sub-period using the analysis of variance sub-program of GENSTAT (release 4.04B, Lawes Agricultural Trust, Rothamsted Experimental Station, 1984). The effects of sheep and period were taken into account in the analysis. The data for rumen volume, outflow rate from the

rumen and foam content in the rumen were analysed in the same manner as the intake data.

RESULTS (Section 7.3)

The chemical composition of the rape was similar over the six periods and is given in Table 7.1. In general the rape had lower N (21 to 25 g N kg^{-1} DM), ADL (8.4 to 10.5 g ADL kg^{-1} DM) and SMCO contents (4.5 to 6.8 g SMCO kg^{-1} DM) than in previous experiments. There were no significant ($P > 0.05$) differences between Group A and Group B lambs in their response, in terms of voluntary intake, to the treatments and therefore, the mean voluntary intake of OM of all the lambs for each treatment is given in Table 7.2. Voluntary intakes of OM remained constant over the first five periods of the experiment but there was a significant ($P < 0.001$) decline in the last period. There were no significant difference between the treatments in the voluntary intake of OM.

Since there were no period or period x treatment effects for the rumen data, the means for each treatment are given in Tables 7.3 and 7.4. The estimates of the amount of foam release through the rumen cannula of the fistulate lambs is given in Table 7.3. The rudimentary nature of the measurement is shown by the higher coefficient of variation (24.6%) compared to that for voluntary intake (13.5%). However, despite this large variation, there was a significant ($P < 0.01$) decline in the amount of foam released through the rumen cannula between the lambs on the control treatment and those given either the pan scourer or surfactant treatments. The proportions of solid present in the total amount of foam released were, however, similar. The mean values over the experiment for rumen liquid volume, outflow rate of liquid and liquid fractional outflow rate from the rumen are given in

TABLE 7.1. Chemical composition of rape offered to lambs during the experimental period.

		DM ($g\ kg^{-1}$)	ASH ($g\ kg^{-1}$DM)	N ($g\ kg^{-1}$DM)	NDF ($g\ kg^{-1}$DM)	ADF ($g\ kg^{-1}$DM)	ADL ($g\ kg^{-1}$DM)	SMCO ($g\ kg^{-1}$ DM)	Total glucosinolates ($mg\ 100g^{-1}$DM)
Period	1	126	136	21.5	201	186	10.4	4.5	12.3
	2	128	164	25.4	218	194	9.3	4.5	12.0
	3	125	125	20.6	194	169	9.5	4.8	13.8
	4	131	156	21.4	219	198	8.7	6.4	12.0
	5	124	119	21.3	207	174	8.4	5.8	11.8
	6	114	149	24.5	218	197	10.5	6.8	11.5

TABLE 7.2. Mean voluntary intake of rape by lambs

	Control ($gOMday^{-1}$)	Pan Scourers ($gOMday^{-1}$)	Surfactant ($gOMday^{-1}$)	s.e.
Period 1	768	783	770	27.6
2	780	773	740	39.1
3	787	753	764	39.0
4	748	761	785	40.7
5	775	749	754	38.4
6	723	675	718	36.9
Overall mean	763	749	756	32.3

TABLE 7.3. The mean quantity of foam released over 60 seconds (means of 5 days).

	Control	Pan Scourers	Surfactant	s.e.
Amount of foam released ($g\ min^{-1}$)	258	188	86	21.8
Proportions of solid matter in foam	0.66	0.56	0.64	0.051

Table 7.4. There were no significant differences between the treatments in rumen liquid volume or liquid outflow rate from the rumen. The lambs on the pan scourer treatment had a significantly ($P < 0.05$) higher liquid fractional outflow rate than the control animals. The effect of the surfactant was to significantly ($P < 0.05$) decrease the liquid fractional outflow rate.

The data for individual animals used to derive all the means in this experiment is given in Appendix Tables 7.1 and 7.2.

DISCUSSION (Section 7.4)

The purpose of this experiment was to investigate the influence of foam in the rumen on voluntary intake of a forage brassica diet by lambs. The factors contributing to the presence of foam in the rumen were also examined. Observations of foam content in the rumen of lambs in Experiment 1 (section 3) showed that leaf diets produced a larger quantity of foam than either stem or bulb components, and therefore the use of a leaf component was envisaged for this experiment. Owing to the adverse weather conditions during the growing period, the rape crop did not mature, necessitating the use of the whole crop. In comparison to the rape components in Experiment 1 the composition rape diet offered in the study was more akin to that of rape leaf than that of the stem component, particularly in terms of DM, NDF, ADF and ADL. This was due to the rape crop having very short (20-30cm), thin stems, and the majority of the plant material being associated with the leaf components. The amount of foam observed in the rumen in this experiment was similar to that noted for rape leaf in Experiment 1.

The two methods of foam reduction were both effective in reducing the apparent quantity of foam in the rumen, the surfactant being more

TABLE 7.4. Rumen liquid volume, liquid outflow rate and fractional liquid outflow rate from rumen (mean of 5 days).

	Control	Pan Scourers	Surfactant	s.e.
Rumen liquid volume (l)	2.85	2.45	2.65	0.323
Outflow rate ($g\ h^{-1}$)	452	423	394	48.7
Fractional outflow rate of liquid from rumen	0.162	0.178	0.150	0.0061

effective than that of the pan scourers. The reduction in apparent foam content in the rumen with the pan scourers suggests that the foam may at least in part, be due to a lack of tactile stimuli on the rumen wall. Cole and Mead (1943) attributed the occurance of bloat in ruminants fed ground alfalfa hay to the absence of the coarse, sharp material necessary to stimulate nerve fibres terminating in the ruminal mucosa. Observations on the presence of the pan scourers in the rumen of the Group B lambs after the experiment showed that all were still present in the rumen with a quantity of fibrous material trapped within the mesh. The fibrous material within the pan scourer may have possibly increased the effectiveness of the treatment.

In addition to decreasing foam content in the rumen, the effect of the pan scourers was to reduce rumen volume, although not significantly, and to significantly ($P < 0.05$) increase the liquid fractional outflow rate from the rumen. Tactile stimuli on the rumen wall may have been involved in increasing rumen motiliy and thereby increasing fractional outflow rate from the rumen.

Poloxalene, a poly-oxypropylene-polyoxyethylene block polymer is a low foam detergent. Laby (1975) describes the action of surfactants as activating the naturally occurring anti-foaming agents in the rumen (principally lipids and their degradation products) previously rendered inactive during the onset of bloat. This activation is achieved by the wetting of surfaces (plant, fragments, etc) and the suspension or emulsification in the rumen fluid of the fatty aggregates liberated by the wetting process. Poloxalene has been shown to prevent bloat with no deleterious effects on feed intake, rumen fermentation, animal health or live weight gain (Clarke and Reid, 1972).

In this experiment poloxalene was very effective in reducing the

apparent foam content in the rumen but it was also associated with a significantly ($P < 0.05$) reduced ruminal fractional outflow rate. This suggests that the presence of foam in the rumen improves rumen motility to some extent acting as a tactile stimuli. Removing all foam could be detrimental to rumen motility in lambs given this treatment.

Although both treatments were effective in reducing foam content in the rumen, neither treatment was associated with an increase in voluntary intake of OM. It is therefore concluded that 1. the presence of foam in the rumen does not contribute to the low voluntary intakes observed in forage brassica diets and 2. that although the ruminal liquid fractional outflow was affected by the treatments, this did not appear to be involved in the control of voluntary intake.

CHAPTER 8 - EXPERIMENT 6

THE EFFECTS ON VOLUNTARY INTAKE AND THYROXINE HORMONE LEVELS OF SUPPLEMENTING LAMBS OFFERED EITHER A BRASSICA OR NON-BRASSICA DIET WITH ALLYLCYANIDE OR 3-ISO-THIOCYANOTOPROP-1-ENE (AGLUCONES OF SINIGRIN)

INTRODUCTION (Section 8.1)

Although no significant correlations existed in Experiment 1 between total glucosinolate content and OM intake, there were significant ($P < 0.05$) negative correlations between individual glucosinolates and OM intake. One of these glucosinolates (allyl glucosinolate, trivial name sinigrin) is the major glucosinolate found in cabbage (Fenwick and Heaney, 1983) and its aglucone products are commercially available. The objective of this experiment was, therefore to make a preliminary examination of the effects of two glucosinolate aglucone products, namely allyl cyanide (nitrile) and 3-iso-thiocyanatoprop-1-ene (isothiocyanate), on the voluntary intake of lambs infused with these products. Voluntary intakes were measured with lambs offered both a brassica and non-brassica diet to identify any possible interactions between the treatments and other components present in the brassica diets that could affect voluntary intakes. Cabbage was used as the brassica diet, in order that the aglucone products infused were the same as those produced by the basal brassica diet. Thyroxine and triiodothyronine levels in the blood were monitored throughout the experiment, as it is known that isothiocyanates are goitrogenic (Fenwick and Heaney, 1983) and this may influence voluntary intakes.

MATERIALS AND METHODS (section 8.2)

The intra-ruminal infusion of the aglucones derived from the hydrolysis of the glucosinolate, sinigrin, (i.e. 3-iso-thiocyanatoprop-1-ene, an isothiocyanate and allyl cyanide, a nitrile) on the voluntary intake by

lambs offered a brassica or a non-brassica diet, viz cabbage or ground and pelleted dried grass, were studied in three experiments. In Experiment A and B, the effect of the intra-ruminal infusion of three levels of isothiocyanate and nitrile respectively on the voluntary intake of ground and pelleted dried grass were examined in a 3 x 3 Latin Square design with three squares in each experiment. In Experiment C, the effect of one of the levels of either the isothiocyanate or the nitrile used in Experiments A and B respectively, on the voluntary intakes of chopped cabbage were compared with that of a control treatment in a 3 x 3 Latin Square design with four squares. Each period was 14 days in duration. Experiments A and B were conducted concurrently and followed by Experiment C. The treatment for each experiment are summarised below:

Experiment A

Control (C) - Continuous intra-ruminal infusion of 120 ml day^{-1} distilled water.

Low (L) - Continuous intra-ruminal infusion of 3-iso-thiocyanatoprop-1-ene at the rate of 1.24 mg kg^{-1} W day^{-1} in 120 ml distilled water.

High (H) - Continuous intra-ruminal infusion of 3-iso-thiocyanatoprop-1-ene at the rate of 2.48 mg kg^{-1} W day^{-1} in 120 ml distilled water.

Experiment B

Control (C) - Continuous intra-ruminal infusion of 120 ml day^{-1} distilled water.

Low (L) - Continuous intra-ruminal infusion of allyl cyanide at the rate of 0.84 mg kg^{-1} W day^{-1} in 120 ml distilled water.

High (H) - Continuous intra-ruminal infusion of allyl cyanide at the rate of 1.68 mg kg^{-1} W in 120 ml distilled water.

Experiment C

1 - Continuous intra-ruminal infusion of 120 ml day^{-1} distilled water.

2 - Continuous intra-ruminal infusion of 3-iso-thiocyanatoprop-1-ene at the rate of 1.24 mg kg^{-1} W day^{-1} in 120 ml distilled water.

3 - Continuous intra-ruminal infusion of allyl cyanide at the rate of 0.84 mg kg^{-1} W day^{-1} in 120 ml distilled water.

The L levels in Experiments A and B were chosen to be equivalent to the amounts produced in the rumen of lambs offered a cabbage diet, assuming that the sinigrin is hydrolysed into equal molar proportions of 3-iso-thiocyanotoprop-1-ene and allyl cyanide. The H levels were chosen to be twice this amount. In Experiment C, the levels infused in Treatments 1 and 2 were designed to lead to the total amounts in the rumen, including that produced from the cabbage corresponding to the H level in Experiment A and B.

The experiments were conducted between September and December, 1985 at the Hill Farming Research Organisation, Bush Estate, Penicuik, Midlothian. There was a two week interval between the end of Experiments A and B and the start of Experiment C.

Animals

Twenty-four Scottish Blackface wether lambs, aged 5 months and weighing 28.4 (s.e. = 0.58) kg at the start of the experiment, were obtained from the Hill Farming Research Organisation's Sourhope Research Station, Yetholm, Roxburgh in early August. In late August,

each was prepared with a rumen cannula (4 cm) as described in Experiment 1 (section 3.2). The lambs were offered dried grass pellets ad libitum from early August.

The lambs were dosed with 1 g copper needles in early July. In early September, all lambs received a clostridial pneumonia vaccination (Heptavac-P, Hoescht) and were dosed with Fenbendazole (Panacur, Hoescht). This was repeated six weeks later in mid-October.

Feeds

The cabbage (cv. Stark Winter) was obtained in October and stored in a cool, frost-free area until required. Prior to feeding, the cabbage was chopped into approximately 3 cm^2 pieces using a root chopper. Samples of both feeds were taken daily for DM determination (oven-dried at 80°C for 24 h). A further sample was bulked over the last week of each period, sub-sampled, stored at -20°C, freeze dried, ground and then analysed for OM, N, NDF, ADF, ADL, SMCO and total glucosinolate contents. The chemical composition of the two diets is given in Table 8.1.

Experimental Procedures and Measurements

Experiments A and B. In a pre-experimental period of one week, the 24 lambs were offered dried grass pellets ad libitum. The eighteen lambs with the highest voluntary intakes were then ranked according to voluntary intake and divided into two equal groups, one half of the lambs being used for each of Experiments A and B. The lambs for each experiment were then allocated to squares according to intake and then randomly allocated a treatment sequence within that square.

Experiment C. All 24 lambs, including those used in Experiment A and B and those not required for those experiments were randomly allocated into two balanced groups according to voluntary intake. One group was

TABLE 8.1. Chemical Composition of diet offered in Experiment 6.

	DM (gkg^{-1})	Ash (gkg^{-1} DM)	N (gkg^{-1} DM)	NDF (gkg^{-1} DM)	ADF (gkg^{-1} DM)	ADL (gkg^{-1} DM)	SMCO (gkg^{-1} DM)	Total Glucosinolates ($mg100g^{-1}$ DM)
Dried Grass Pellets	883	89	21.7	493	290	20.0	1.1	0.0
Cabbage	108	82	27.9	163	116	8.1	12.8	25.1

used in Experiment 5 (Chapter 7) and the other in Experiment C. Those used in Experiment C were accustomed to the chopped cabbage diet over a period of two weeks prior to the commencement of the experiment.

Throughout each experiment the lambs were confined in metabolism crates and each feed was offered at 0.20 in excess of the previous day's intake. The feeds were offered at 0900h and 1600h daily. Refusals were collected daily at 0830h, bulked on a weekly basis and analysed for DM, OM, N, NDF and ADF as described in Experiment 1 (section 3.2).

Infusions commenced on day 5 of each period and daily voluntary intakes were recorded between days 7 and 14. Blood samples were taken on days 1, 7 and 14 of period 1 and days 7 and 14 of periods 2 and 3. The blood samples were centrifuged (3000rpm for 15 minutes) and plasma concentrations of Triiodothyronine (T_3) and Thyroxine (T_4) were determined by radioimmunoassay using a diagnostic kit (Corning Scientific and Medical, Reading). Sensitivity of the T_3 assay was 0.25 $\mu g\ l^{-1}$ and the within-assay coefficient of variation was 9% (n=9). Sensitivity of the T_4 assay was 12.5 $\mu g\ l^{-1}$ and the within-assay coefficient of variation was 13% (n=7). All blood samples were analysed in one assay.

The voluntary intake and hormone data were statistically analysed using the analysis of variance sub-program of GENSTAT (release 4.04B, Lawes Agricultural Trust, Rothamsted Experimental Station, 1984). The effects of square, period, sheep and previous treatment were taken into account in the analysis of variance. With the data on T_3 and T_4 concentrations on days 7 and 14, the values for day 1 of each period were used as a covariate.

RESULTS (Section 8.3)

There was no period x treatment interactions in any of the data

TABLE 8.2. The voluntary intake of OM($gday^{-1}$) by lambs offered dried grass pellets in Experiments A and B

	Treatment			
	0	L	H	s.e.
Experiment A	1049	1005	978	69.6
(infusion of 3-iso-thiocyanatoprop-1-ene)				
Experiment B	986	1074	974	56.8
(infusion of allyl cyanide)				

TABLE 8.3. The voluntary intake of OM($gday^{-1}$) by lambs offered cabbage in Experiment C

	Treatment			
	1 (Control)	2 (Isothiocyanate)	3 (Nitrite)	s.e.
Period 1	630	336	712	
2	517	508	507	71.3
3	554	580	436	
Mean	567	475	552	41.2

TABLE 8.4. Mean concentrations of T_3 and T_4 ($\mu g l^{-1}$) in the plasma of lambs offered dried grass pellets in Experiment A (mean values for days 7 and 14 adjusted for covariate of concentration in day 1).

	T_3			T_4		
	Day			Day		
	1	7	14	1	7	14
Treatment						
0	1.30	1.41	1.90	68	83	92
L	1.69	1.45	1.60	74	70	71
H	1.83	1.51	1.79	69	85	95
s.e.	0.084	0.149	0.178	4.9	8.0	8.7

TABLE 8.5. Mean concentration of T_3 and T_4 ($\mu g l^{-1}$) in the plasma of lambs offered dried grass pellets in Experiment B (mean values for days 7 and 14 adjusted for covariate of concentration in day 1)

	T_3			T_4		
	Day			Day		
	1	7	14	1	7	14
Treatment						
0	2.58	1.61	1.96	88	79	83
L	1.54	1.64	2.11	78	75	93
H	1.92	1.60	1.83	72	82	106
s.e.	0.226	0.205	0.181	7.5	8.0	13.9

TABLE 8.6. Mean concentration of T_3 and T_4 ($\mu g l^{-1}$) in the plasma of lambs offered cabbage in Experiment C (mean values for days 7 and 14 adjusted for covariate of concentration in day 1).

	T_3			T_4		
	Day			Day		
	1	7	14	1	7	14
Treatment						
1	1.65	1.63	1.50	58	39	43
2	1.56	1.98	1.96	63	46	48
3	1.72	1.72	1.45	57	47	46
s.e.	0.124	0.088	0.110	6.1	3.3	4.4

with the exception of the data on voluntary intake in Experiment C. Consequently, with the exception of that data set the overall treatment means are given for the variables measured. The voluntary intakes of OM by lambs in Experiment A and B are given in Table 8.2. There were no significant ($P > 0.05$) effects of the intraruminal infusions of either the isothiocyanate or the nitrile on voluntary intakes of OM. When the L treatments of both aglucones were administered to lambs offered a chopped cabbage diet in Experiment C, there was a significant ($P < 0.05$) period x treatment effect (Table 8.3) which was due to the voluntary intake of lambs given the isothiocyanate treatment being lower than that of the other treatments in period 1 and the voluntary intake of lambs given the nitrile treatment being lower in period 3 than in period 1 and 2.

The treatment means of concentrations of T_3 and T_4 in plasma in Experiments A, B and C are given in Tables 8.4, 8.5 and 8.6 respectively. There were no significant differences between treatment in either T_3 or T_4 concentrations in plasma on days 1, 7 or 14 in Experiment A. There was a significant ($P < 0.05$) period effect of T_3 concentration in plasma measured on day 7 with concentrations in period 1 being lower than in periods 2 and 3 (1.06 vs 1.66 ng ml^{-1}, s.e. 0.153). There were no differences between periods in the concentration of T_3 in plasma measured on day 14 or for T_4.

There was no significant differences in Experiment B between treatments in the concentrations of T_3 or T_4 in plasma (Table 8.5). However, as in Experiment A, there was a significant ($P < 0.01$) period effect with concentrations of T_3 in plasma on day 7 in Period 1 being lower than in either periods 2 or 3 (1.06 vs 1.90 ng ml^{-1}, s.e. 0.182). There was also a significant ($P < 0.05$) period effect, with plasma

concentrations of T_4 on day 7 in period 3 having a higher concentration than in either periods 1 or 2 (99 vs 68 ng ml^{-1} s.e. 9.7). In both cases, however, the period effects were not significant on day 14.

In Experiment C, there were significant ($P < 0.05$) treatment effects with lambs given the isothiocyanate treatment having higher plasma T_3 concentrations on both days 7 and 14. There were also significant ($P < 0.01$) period effects with plasma T_3 concentrations on day 7 being lower in periods 1 and 2 than in period 3 (1.64 vs 2.06 ng ml^{-1} s.e. 0.098) and on day 14 being lower in periods 2 and 3 than in period 1 (1.40 vs 2.12 s.e. 0.122). There were no significant treatment or period effects on the concentration of T_4 with lambs in Experiment C.

The data for individual animals, used to derive all the means in this experiment is given in Appendix Tables 8.1, 8.2 and 8.3.

DISCUSSION (Section 8.4)

The objective of this experiment was to assess the effects on voluntary intake of two aglucone products obtained from the hydrolysis of the glucosinolate, sinigrin. These were administered to lambs offered either a non-brassica or brassica diet to enable any interactions with other compounds in the brassica diet to be identified.

Although no formal statistical comparisons can be made between the data from Experiment A and B (non-brassica diet) and from Experiment C (brassica diet), it is clear that voluntary intakes were higher when the lambs were offered the dried grass pellets rather than the cabbage diet. This is in agreement with other experiments comparing intakes of brassica and non-brassica diets (eg Jagusch et al 1977; Barry et al, 1982). The chemical composition of the two diets (Table 8.1) showed that they had similar ash and N contents but the

cabbage had a lower content of structural carbohydrate and a higher amounts of sulphur compounds. Experiment 5 (Chapter 7) pointed to the lack of effect of structural carbohydrate content in brassica diet on voluntary intake and therefore it is very likely that the depression in intake is a function of the presence of the sulphur compounds. This theory is supported by the decline in T_4 plasma concentrations when the lambs were offered the cabbage compared to the dried grass pellet diets, an observation also reported by Barry et al (1983a) in lambs grazing either kale or a ryegrass-clover sward.

Neither of the aglucone products influenced voluntary intake of dried grass pellets at the levels infused. However when offered the cabbage diet, there was a significant ($P < 0.05$) depression in voluntary intake in lambs administered the infusion of 3-iso-thiocyanatoprop-1-ene in period 1 and also a significant ($P < 0.05$) depression in voluntary intake in lambs administered the allyl cyanide in period 3. One possible explanation is that there was a variable production of isothiocyanates and nitrites from the glucosinolates in cabbage over time in Experiment C, possibly as a result of adaptation within the rumen, with a greater proportion than the 0.50 predicted of the glucosinolates present in the cabbage being hydrolysed to isothiocyanate in period 1 and nitrile in period 3 than in other periods. This would lead to greater amounts of isothiocyanate in period 1 and nitrile in period 3 being present in the rumen of the lambs than in Treatment 1 in Experiments A and B respectively. Although this is a possible explanation for the low intakes observed in Experiment C, there is no corroborative evidence, as the fate of glucosinolates in the rumen is not well understood (see review by Tookey et al, 1980).

An alternative explanation is that some other factor present in

forage brassicas is interacting with the glucosinolate aglucones to depress voluntary intake. The most probably candidate on current evidence is SMCO, although aglucones other than the one studied in this experiment could also have been involved. The hydrolysis product of SMCO in the rumen, dimethyl disulphide, is responsible for haemolytic anaemia and has been implicated in low voluntary intakes by lambs consuming forage brassicas (Smith, 1974; Barry et al 1982). However, Barry (1978) noted in a review on the factors governing the nutritive value of brassica crops that sheep consuming swedes did not suffer so severe an anaemia as those consuming kale, despite similar SMCO concentrations. Also, in a later experiment, Barry et al (1982) showed that animals consuming kale had a much larger depression in intake than those consuming lucerne at similar SMCO intakes, using synthetic SMCO. Neither study considered the possibility of glucosinolates being responsible for these observations. Swedes, although having a similar total glucosinolate content to kale (Chapter 3; Bradshaw et al, 1984), have a different glucosinolate profile and the results of Experiment 1 indicated that only certain glucosinolates were correlated with intake. Furthermore, Bradshaw et al (1984) could find no traces of sinigrin in swedes but in kale leaf and stem, there are appreciable quantities 3.25 ($\pm$ 0.597) and 5.52 ($\pm$ 1.26) mmolkg^{-1} DM for kale leaf and stem respectively. The presence of glucosinolates may also account for the different responses in voluntary intake by lambs of lucerne and kale in the experiment of Barry et al (1982), as lucerne contains no glucosinolates.

In the present experiment, the dried grass pellets contained negligible amounts of SMCO. The cabbage, however contained considerable concentrations of SMCO and thus the SMCO and the isothiocyanate, derived from sinigrin, could have together caused the

reduction in voluntary intake observed in period 1 of Experiment C. It however does not account for the low voluntary intakes in period 3 of Experiment C when allyl cyanide was infused.

Isothiocyanate acts as a reducing agent and the most probable action of it, together with SMCO, would be to inactivate glucothione, thereby making it unable to convert methaemaglobin to haemaglobin, resulting in the production of Heinz bodies. Barry et al (1985) linked the action of SMCO, in particular, with the depression in voluntary intake and liveweight gain observed in the first six weeks of being introduced to brassica diets. They suggested that the animals thereafter adapted to diets containing SMCO. In Experiment C, because of the two week introduction to the crop, voluntary intakes in the first and second periods were actually measured in week 4 and 6 respectively after introduction to the crop. It is therefore possible that by the second period, the lambs had become adapted to the SMCO in the diet and therefore the combined effects of SMCO and isothiocyanate on voluntary intake would not have been so large. Barry et al (1985) linked the process of adaptation to increases in plasma concentrations of Growth Hormone and T_4. However, this was not apparent in this experiment.

Plasma concentrations of T_3 were higher in animals given isothiocyanate than in control animals in Experiment C but not in Experiment A. 3-iso-thiocyanatoprop-1-ene has been reported to inhibit protein synthesis in in vitro tissue studies (Leblova, 1965) and to inhibit incorporation of [^{14}C] leucine into microsomal proteins in rat liver (Alam and Ahmad, 1970). This evidence suggests that 3-isothiocyanatoprop-1-ene may inhibit protein synthesis in ruminants. The presence of T_3 has been shown to stimulate the sythesis of messenger RNA and protein synthesis and phosphoralation (De Groot et al, 1980). If protein synthesis

were inhibited by 3-iso-thiocyanatoprop-1-ene, the lambs may have increased the production of T_3 and this could have led to an increase in T_3 concentration as was observed in Experiment C. Why this was only apparent in Experiment C and not Experiment A is probably due to the presence of SMCO in cabbage and an additive effect on T_3 production.

In all three experiments, T_3 concentrations on day 7 were significantly ($P < 0.05$) lower in period 1 than in periods 2 and 3. No explanation can be found for this observation but as it occurred in all experiments, irrespective of treatment, it is probably not due to the treatments imposed, but rather due to other factors. As expected the nitrile had no effect on T_3 or T_4 concentrations, as they are not goitrogenic.

CHAPTER 9 - GENERAL DISCUSSION

Experimental Approach (Section 9.1)

The utilisation of the majority of forage brassicas traditionally has occurred and is likely to continue to occur under grazing conditions. This is due to the high labour requirements in a cut and carry system and the high capital cost of housing animals, particularly with low dry matter crops which produce large volumes of urine. However, most of the experiments conducted on forage brassicas have been conducted indoors including several in this thesis and it is important to examine the assumptions that underly the extrapolation from indoor experiments to grazing conditions. In Experiment 1, voluntary intakes of the crops were measured and intake was related in this experiment and also in Experiment 2 to the disappearance of OM in the rumen and NAN flow rates of the abomasum. In Experiments 5 and 6 voluntary intakes were also studied.

The assumption underlying the measurement of voluntary intake are that the plant parts selected by the grazing lamb will be similar to those harvested and offered to lambs indoors, that the structure of the crop grazed *in situ* does not have a large influence on intake and that the process of harvesting and feeding the crop does not lead to large changes in the chemical composition of the plant. None of these assumptions were directly tested in the experiments conducted. However the experiment of Armstrong *et al* (1984) suggested that there was little difference between voluntary intakes measured indoors and intake values obtained with grazing animals. Care was taken to offer only those plants observed to be grazed by lambs and the harvested material was offered fresh rather than in a dried or frozen and thawed form. Consequently, it is argued that the extrapolation of voluntary intakes to the intakes of grazing lambs can be justified.

Furthermore, there are considerable difficulties in the accurate measurement of intake by lambs grazing forage brassica crops. The results of the comparison between the two methods of estimating intake in Experiment 3 highlight the problems involved in accurately measuring intake under grazing conditions. Direct observations indicated that samples of extrusa from oesophageal fistulated lambs may not be truly representative of the crop consumed by entire lambs and in the case of the method based on estimating the indigestibility of the crop from the extrusa samples, the small errors in estimating digestibility can lead to possible biases and errors in the estimation of intake. For example, the coefficients of variation in intake was much higher (CV = 19.5%) compared to that found in an indoor experiment such as Experiment 6 (CV = 10.6%).

It is argued that the large coefficients are attributable to greater errors in measuring intake by the grazing lamb, rather than due to greater actual variation in intake by grazing lambs than those housed indoors. In consequence, larger numbers of animals require to be used to identify significant differences between treatments. Indeed, in the grazing experiments reported here, larger numbers of animals per treatment were required to show statistical significance, even though the differences observed were of important biological and agricultural significance. The method based on the n-alkane method of Mayes et al (1986) has potential advantages, particularly in estimating intakes of grazing lambs when supplements are offered. However, the large difference between the n-alkane composition of stem and leaf components makes it crucial that the dietary sample analyses are truly representative of what is ingested. This is a particular problem with leaf and stem crops, but also applies to a lesser extent when bulb and

leaf components are both ingested. Further research on obtaining representative samples of the diet ingested and the seeking of different naturally occurring markers would be desirable.

Measurements of digesta flow similar to those taken in Experiments 1 and 2 have been made outdoors (e.g. Milne et al, unpublished data), using portable infusion pumps mounted on the animal. The pump infuses the marker at a constant rate into the rumen in a similar manner to that described in Experiment 1. Rumen and abomasal samples are then collected manually or automatically (Evans, et al, 1981) and voluntary intake is measured as described in Experiment 3. The principal disadvantage of this methodology, apart from the errors involved in estimating intake, are that the steady state conditions required for the measurement assumptions to be met (Faichney, 1975) may not be met with the pattern of daily intake of grazing lambs and which can obviously be more easily controlled indoors. In addition, particularly in the case of the tall crops such as rape and kale, the portable infusion pump is vulnerable to damage. For the reasons above most of the experiments reported here were conducted indoors where the measurements could be more easily made but where the assumptions involved in extrapolating to grazing conditions are tenable.

Scottish Blackface lambs were used in all the brassica experiments reported. This reflects the fact that each year approximately half a million Scottish Blackface lambs are sold from hill farms to upland and lowland farms for finishing. All the lambs used in these experiments were representative of the Lanark strain of the Scottish Blackface breed. There is no evidence of interactions between feed and strain types although strains do have differences in, for example, the rate of finishing on the same crop (Doney et al, 1988). Consequently the results

of these studies should have a wide application to the Scottish Blackface breed.

Nutrient Supply (Section 9.2)

The data from Experiment 1 has led to an increase in the quantitative understanding of the nutritive value of a range of forage brassicas. In particular, knowledge of the amount of digestible OM apparently digested in the rumen and of NAN flowing past the abomasum, hitherto unavailable, made it possible to examine which nutrients limit tissue gain in lambs offered these crops. It was concluded that with leaf and stem components of forage brassicas, the supply of energy substrates limited tissue gain, whereas with the bulb components tissue gain was limited by N supply. Some of these hypotheses were tested in Experiments 2 and 3 using cereal and protein supplements, and the evidence obtained did not refute the hypotheses tested. However, the responses to supplementation varied between forage brassica crops and bear further examination.

Supplementation (Section 9.3)

In Experiment 2, where intakes were restricted to eliminate any substitution effects, lambs offered rape leaf showed no increase in the amount of nutrients available for absorption following supplementation, whereas lambs offered hybrid turnip leaf had significantly higher ($P < 0.05$) NAN flows at the abomasum. This latter observation was attributed to supplementation altering the N intake as a proportion of the OM apparently digested in the rumen in lambs offered hybrid turnip but not rape leaf. On this evidence, the conditions where cereal or rumen degradable protein supplementation would improve tissue gain in lambs offered rape leaf are very few and perhaps accounts for the poor response to supplementation in Experiment 3 although it appeared that

there was a low substitution of forage intake by the supplement in both crops.

With hybrid turnip, the suggested effects of herbage allowance on intake, of supplementation on the ratio of N intake to the proportion of OM apparently digested in the rumen and on carcase gains indicate the value of supplementation. These results indicate that it is difficult to generalise from one forage crop to another and imply that further experiments with grazing animals are required before the response of lambs to supplementation of other forage brassicas can be predicted.

The effect on the concentrations of VFA's and ammonia in the rumen of lambs offered both rape and hybrid turnip crops suggest that the method of supplementation used may not provide the most efficient means of supplying substrates to maximise rumen fermentation. Indeed, in Experiment 2, the efficiency of N capture (estimated as NAN flow at the abomasum per g OM apparently digested in the rumen) was reduced with the cereal supplementation. Following consumption of the supplement, there was a peak in VFA concentration, particularly of propionate, which rapidly decreased to levels similar to those found in unsupplemented lambs. This suggests that the duration in which the supplement was effective was very limited and may account for the limited response in terms of NAN flow past the abomasum.

The length of time in which the supplement was effective in the rumen could be increased by either the supplement being ingested in small quantities over the day or providing the energy in a different and slower releasing form. In such circumstances, the use of feed blocks may have a role as it provides the possibility of ingesting small quantities at one meal. However there could be a difficulty in ensuring that lambs would ingest feed blocks. A second alternative may be

accomplished using feeds with a high structural carbohydrate content, such as a high-quality hay (e.g. Drew, 1968) although, what evidence there is, would suggest a high substitution rate.

The general conclusions that can be drawn are that

1) Substitution rates appear to be relatively low in lambs offered brassica leaf crops but supplementation does not necessarily change the ratio of N intake to digestible organic matter intake. The use of supplements to alter this ratio and thereby improve the efficiency of N use in the rumen to increase NAN flow at the abomasum or to increase the amount of energy substrates absorbed from the rumen is therefore of limited use,

2) The possibility of changing N to carbohydrate ratios of the plant to increase efficiency of use of N in the rumen exists by altering fertiliser or cultural practice or by making it a long-term plant breeding objective. These options ought to be considered further, and

3) The most effective means of increasing the amount of energy substrate supply may be through increasing voluntary intakes.

Voluntary Intakes (Section 9.4)

In addition to providing quantitative information with which to develop hypotheses about nutrient limitations to tissue growth, the results from Experiment 1 highlighted the relatively low voluntary intakes of forage brassicas. This was pursued with the effects of foam and glucosinolates on voluntary intake being examined in Experiments 5 and 6 respectively. Although in Experiment 5 the amount of foam was shown to decrease with the addition of a tactile stimuli to the rumen or by the administration of surfactants, it did not appear to be associated with low intakes. Experiment 6, however, provided some evidence to indicate that glucosinolates or more precisely, the aglucone products of

breakdown in the rumen may influence voluntary intake, although the evidence was inconclusive and only appeared to apply when the lambs were offered a brassica diet. Further research in this area requires to concentrate on the administration of other aglucone products of glucosinolates other than sinigrin, to lambs to assess their effect on voluntary intakes since, at least 15 glucosinolates have been found within the genus Brassicae (Fenwick and Heaney, 1983), their qualitative and quantitative composition depending upon such factors as species, age of plant and plant part. The ultimate products of glucosinolate hydrolysis are dependant upon the chemical structure of the glucosinolate sidechain and the conditions in which the hydrolysis takes place, such as pH and temperature (Tookey et al, 1980). Therefore possible links between intake and a variety of aglucose products require to be established before it may be concluded that glucosinolates have an effect on intake.

The role of SMCO in influencing voluntary intakes has not been examined in this thesis. This was mainly due to there already being an established link between SMCO and voluntary intake (e.g. Barry et al, 1982) albeit at above physiological levels of ingestion. However the results of Experiment 6 suggested a possible link between SMCO and glucosinolates in limiting voluntary intake with the SMCO and isothiocyanate together inactivating glucathione, thereby leading to increased Heinz body formation and reduced intake. The additive effect of aglucone products and SMCO has not been tested experimentally and would therefore be a worthwhile area of research.

Several other possible factors contributing to the low intakes of forage brassicas have not been investigated in this series of experiments. The volume of water consumed has been suggested to be important in limiting voluntary intake (Bradshaw et al 1982). In Experiment 1, the

lambs were consuming up to 11 litres of water each day, approximately one third of their body weight. Normally, water is passed rapidly through the rumen and is absorbed in the colon. However, the water present in forage brassicas is confined within the cell walls, thereby prolonging its residence in the rumen until the cells are broken down and the water released. This may have led to rumen distension and thereby limited intake. Reducing the moisture content without significantly altering the crop structure, would perhaps be a method of testing this theory. Wilting the crop prior to feeding would be the most obvious method of reducing moisture content but may also result in changes in chemical composition which would have to be taken into account.

It was suggested that VFA production rates were higher for forage brassicas crops per unit of intake than for non-brassica herbage diets (Chapter 3). This may have resulted in intake being limited by a negative feedback mechanism as reviewed by Forbes (1986). However, as VFA production rates were not actually measured but only estimated in Experiment 1, this link can only be suggested and would require testing in the first instance by measuring VFA production rates in the rumen of lambs ingesting forage brassicas. The method of assessing the role of VFA production rates on voluntary intakes would be very difficult to assess, suffering from the same deficiencies as those of Baile and Mayer (1969) where the effect on voluntary intake of one VFA could not be assessed in isolation, with factors such as other VFA's present and rumen pH being involved.

Bulb Crops (Section 9.5)

The nutritive value of the bulb components of forage brassicas was not examined beyond Experiment 1. It was considered more profitable to pursue research on the nutritive value of the leaf components

thoroughly rather than to deal with all components more superficially. The review of literature (Chapter 2) highlighted the fact that bulb components, and in particular swedes, have a low N content. The results of Experiment 1 suggested that NAN flows past the abomasum in lambs ingesting bulb components was limited by N intake. Similar experiments to Experiments 2 and 3 conducted with bulb components would test this hypothesis. In addition to the possible factors affecting the intake of leaf components, there may be other factors limiting the intake of bulb components. These include teeth loss as a result of the hardness of the bulb, making it difficult for the lambs to prehend the crop (e.g. Drew, 1968) . Fitzgerald, (1971) showed that offering the bulb in a chopped form increased voluntary intake, but did not relate this to teeth loss. Other factors such as grazing time and maximum bite weight in lambs grazing bulb components would have to be examined before low intakes, due to teeth loss could be confirmed.

Soil contamination and subsequent ingestion is a greater problem with bulb components than leaf or stem components due to the crop structure, lowering the acceptability of the crop and possibly reducing voluntary intake. Evidence for this comes from Bastiman and Slade (1978) who reported higher wastage of swede crops in wet seasons than dry seasons. Offering bulb components with variable soil contents to lambs and measuring intake would serve to test this theory. However, variable soil contamination would also lead to variable trace element intakes.

The possibility of trace element deficiency affecting intake or tissue gain has not been examined thoroughly. Barry et al (1981b) reported that the content of truly available copper per kg plot DM was lower for kale than for pasture diets since the copper concentration in

kale was only about one third of that in pasture and also due to the much higher sulphur content in kale, the percentage true availability of copper could be depressed (Suttle and McLaughlan, 1976). In cattle offered kale diets, copper supplementation increased liveweight gain and reduced Heinz body formation (Barry et al, 1981b). However, when a similar experiment was conducted with lambs, no response in terms of liveweight gain or Heinz body formation were observed (Barry et al, 1983b) possibly due to their lower requirements of copper for growth (Suttle, 1976). In the experiments reported here all lambs were administered copper needles prior to commencement of the experiment to counteract any possible copper deficiencies. This is reflected in plasma copper concentrations being in the range 60 to 100 ug 100 ml^{-1} which is within the normal range for lambs of this age. As all lambs in this experiment were given copper supplementation, the results of these experiments cannot verify any possible copper deficiency problems in lambs grazing forage brassicas. As no studies have been conducted on other trace elements, no conclusion can be reached as to the role of other trace elements in limiting intake or tissue gain and further research is required in this area.

Future Role of Forage Brassicas in the Sheep Industry (Section 9.6)

A surprising observation to emerge from the carcase data in Experiment 3 was the lower amounts of fat and lower proportions of fat in the carcase at slaughter of the lambs grazing hybrid turnip than rape leaf despite similar total protein weights. If these differences are confirmed and the reasons for the differences established, it would have important ramifications in present production systems, where carcases are required to be leaner but not of lighter weights.

Forage brassicas may become a more important crop in the next

ten years than they have in the past few decades. They provide a source of inexpensive nutrients at a time of year when the nutritive value of pasture is declining and is scarce. The seasonal nature of lamb production has always resulted in lower lamb prices in late summer and autumn than at other times of the year. The possibility of the removal of the EEC variable premium scheme will provide a greater financial incentive to slaughter lambs in January or February. To avoid damage to pastures, lambs will require to be housed and fed on conserved forage and cereal diets. Housing in livestock enterprises is always expensive and the only other likely alternative is the utilisation of forage brassicas by grazing, in the period from December to March.

The advent of dairy quotas and grain surpluses has led to the investigation of alternative enterprises to complement existing ones. In the future, forage brassicas could be a realistic proposition with producers buying lambs from hill flocks and finishing them on land that would have previously been used for grain or grass for the dairy cow. Forage brassicas have several favourable factors for lowland farmers. They do not require specialised equipment and they do not compete for labour at peak times. Soil fertility is improved from the plant residues and excreta and in areas where oilseed rape is not grown, they also provide a break in crop rotation, thus reducing the risk of disease build-up.

One of the major disadvantages to the use of forage brasicas, in animal production systems is the unpredictability of crop yield. Poor germination or slow seedling growth can lead to poor yields or total failure of the crop with the herbicides in current use not being totally effective in controlling weeds and therefore compete with the sown crop, leading to poor yields. In terms of systems of animal production, at

present, the major disadvantage is our inability to predict the intake, utilisation, growth rate or finishing date of the lambs at the start of a grazing period. This can lead to either under-utilisation of the crop or lambs not being finished when the crop is exhausted. Unless it is possible to predict accurately, barring abnormal weather conditions, the yield and the utilisation of crops, forage brassicas will not be looked upon as a viable alternative system. This therefore identifies areas of research that require to be undertaken to enable systems using forage brasicas to be more predictable and reliable.

There is also a need to develop more frost hardy cultivers enabling prolonged utilisation of forage brassicas over the winter period. Some headway has been made in this direction, such as the development of the Maris Kestrel variety of marrow stem kale which has been described as more frost hardy than its counterparts (McNaughton and Ross,1978). New more frost hardy varieties of rape and cabbage have also been developed (Macfarlane Smith, W. pers. comm.) but their nutritive value has yet to be tested.

In terms of research into the nutritive value of forage brassicas the factors which control intake of forage brassicas remain the most important factor to be elucidated. Only a limited number of possible factors have been examined within the confines of this thesis and other factors require to be examined before accurate predictions of intake can be made. It may not always advantageous for producers to maximise intake as in the case where lambs are required to be finished over a period of months. However in these circumstances it is still important to be able to predict levels of nutrient supply and performance in the production of lambs to meet market requirements.

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APPENDIX 1: A COMPARISON OF THE FATE OF ^{35}S IN THE DIGESTIVE TRACT OF LAMBS OFFERED EITHER A BRASSICA OR NON BRASSICA DIET

INTRODUCTION

The use of the method of Mathers and Miller (1980) to estimate microbial production rate in the rumen of lambs offered forage brassica diets in Experiment 1 appeared to give unsatisfactory values (see Section 3.4). It was suggested that the ^{35}S label of sodium ^{35}sulphate could have become incorporated into organic compounds such as the aglucone products of glucosinolate hydrolysis or dimethyl disulphide as well as microbial protein. The object of this series of observations was to examine in more detail this hypothesis. As it was not possible to isolate and identify the possible S-containing compounds present in rumen and abomasal digesta, the hypothesis was tested by comparing the presence of ^{35}S in solid, liquid and microbial digesta fractions of sheep offered a brassica diet (swedes) with those of sheep offered a non-brassica diet which contained zero or negligible amounts of SMCO or glucosinolates.

In the first series of observations, which were made during Experiment 2 (Section 4), samples of rumen and abomasal digesta from lambs offered a brassica diet were obtained following the infusion of sodium ^{35}sulphate. The presence of ^{35}S in the different digesta fractions after inorganic sulphur and microbial protein had been removed was then compared with that from rumen samples taken from sheep offered a non-brassica diet. In a further series of observations, the presence of ^{35}S in rumen and abomasal fractions of sheep given either a non-brassica (hay) or brassica (swedes) diet were compared.

MATERIALS AND METHODS

Sample Collection

Samples of rumen and abomasal digesta were collected from the 12

lambs offered rape and hybrid turnip leaf in Experiment 2. Thirty-six hours prior to the first sampling of rumen and abomasal contents, ^{35}S as sodium ^{35}sulphate was continuously infused intraruminally at the rate of 80 uCi ^{35}S per day. After the last sample on the second sampling day of each period had been taken, approximately 100 ml of rumen liquor was collected from each of the 12 animals using the same technique as outlined in Section 3.2. The rumen liquor samples were acidified with 10 drops of concentrated sulphuric acid and frozen at -20°C until analysed. Solid, liquid and microbial fractions of abomasal digesta were obtained as the remainder of the samples collected during Experiment 2 and which were not required in that experiment.

Two mature Greyface ewes which had previously been prepared with a rumen cannula were offered for seven days prior to rumen liquor collection, a complete pelleted diet (AA6; Wainman et al, 1970) (mean intake 608 g DM day^{-1}). Sodium ^{35}sulphate was continuously infused at the rate of 80 μCi ^{35}S per day; 36 hours prior to 200 ml of rumen liquor being collected. The liquor was acidified and frozen at -20°C until analysed.

In further observations, four mature Scottish Blackface wethers (mean weight 65 (s.e. = 2.1) kg), which had previously been prepared with rumen and abomasal cannulae, were used to compare the ^{35}S content in rumen liquor and abomasal digesta fractions when the sheep were offered either hay or swede diets ad libitum (mean intakes: hay 820 and 605 g DM day^{-1} for hay and swede diets respectively) in a simple cross-over design. There was a ten-day interval between the two periods, which were of seven days duration.

The amounts and infusion time of ^{35}S was the same as in previous experiments with 200 ml of abomasal digesta and 100 ml of rumen liquor

being collected at four hourly intervals over 24h at the end of each period. The abomasal digesta was processed by the same method as that described in Section 3.2. The rumen liquid was acidified and frozen at -20°C until analysed. The chemical composition of the diets is given in Table Ap 1.1.

Preparation of digesta samples

Rumen liquor. The rumen liquor samples were defrosted completely and thoroughly mixed. Aliquots of the liquor (9 ml) were centrifuged for 30 minutes at 19,500 r.p.m. to separate particulate matter and microbial material from the supernatant. One ml of the supernatant was counted as described in Chapter 3 (counts A). To 5 ml of the remaining supernatant was added 1 ml of a solution containing 0.1M Sodium Sulphide and 0.1M Sodium Sulphite. One ml of 0.2M Barium Chloride was also added to precipitate out the inorganic Sulphide and Sulphite present in the liquor. Inorganic Sulphate and any remaining protein was precipitated out by adding to the supernatant 1 ml each of 5% Zinc Sulphate and 0.15M Barium Hydroxide. The supernatant was then centrifuged at 19500 r.p.m. for 30 minutes to remove the inorganic Sulphur and proteins from the liquor, and 1 ml of the resultant supernatant was counted (counts B). A further 5 ml of this supernatant was then subjected to acid hydrolysis, as in the technique of Mathers and Miller (1980) (Section 3.2), with 1 ml of the resultant supernatant being counted (counts C).

Abomasal digesta fractions. The abomasal digesta fractions were subjected to the same process as the rumen samples. Prior to analysis the freeze-dried digesta fractions were reconstituted by 0.5 g of the digesta being mixed with 10 ml distilled water and left for 24h before being centrifuged.

TABLE Ap1.1. Composition of diets offered.

	DM	ASH (gkg^{-1} DM)	N (gkg^{-1} DM)	NDF (gkg^{-1} DM)	ADF (gkg^{-1} DM)	ADL (gkg^{-1} DM)	SMCO (gkg^{-1} DM)	SCN ($mg\ kg^{-1}$)
Swede	120	98	17.3	170	156	10.4	6.5	12.2
Hay	829	55	12.0	649	378	39.0	0.5	-
Pelleted Complete diet (AA6)	872	93	20.6	428	224	31.1	0.5	-

RESULTS

The number of disintegrations ml^{-1} of rumen liquor of the lambs in Experiment 2 that were present after the inorganic Sulphur had been removed, as a proportion of the disintegrations ml^{-1} after the initial centrifugation (counts B - counts A), which was taken to be the proportion of soluble ^{35}S present in non-protein organic Sulphur in the supernatant, was 0.42 (s.e. = 0.024, n = 28). There was no difference between the two crops or between the supplemented and unsupplemented treatments. After acid hydrolysis, the proportion (counts C - counts A) was reduced to 0.077 (s.e. 0.0036, n = 5). The proportion of disintegrations ml^{-1} that are assumed to be associated with non-protein organic compounds in the rumen liquor of sheep offered the complete diet was 0.17 (n = 2). This was reduced to 0.008 (n = 2) after acid hydrolysis.

In the comparisons between the swede and hay diets, the proportion of ^{35}S before acid hydrolysis, in the non-protein organic Sulphur compounds in the supernatant, were 0.17 and 0.08 for the swede and hay diets respectively (see Table Ap 1.3). After acid hydrolysis the proportions were 0.07 and 0.03 for the swede and hay diets respectively.

The same proportions were calculated for the whole, precipitate and microbial fractions of abomasal digesta and are presented in Tables Ap 1.2 and 1.3. In Experiment 2 the proportion of organic Sulphur present before acid hydrolysis (column 1) was generally higher than that found for the rumen liquor data. The proportions of disintegrations ml^{-1} remaining after hydrolysis (column 2) were also higher than those observed with the rumen liquor data.

The proportion of counts present before acid hydrolysis (counts B - counts A) in the wethers offered the hay diet was approximately 0.50 of those present in the wethers offered the swede diet. The difference

TABLE Ap1.2. The proportion of counts in abomasal and rumen liquor samples from Experiment 2 that are assumed to be organic ^{35} sulphur.

	Counts B / Counts A	s.e.	(n)	Counts C / Counts A	s.e.	(n)
Abomasal						
Whole	0.59	0.027	(11)	0.48	0.040	(11)
Precipitate	0.50	0.022	(9)	0.27	0.032	(9)
Microbial	0.65	0.026	(10)	0.23	0.019	(10)
Rumen liquor	0.42	0.024	(28)	0.077	0.036	(5)

TABLE Ap1.3. The proportion of counts in abomasal and rumen liquor samples from Experiment C that are assumed to be organic ^{35} sulphur.

	Counts B / Counts A		Counts C / Counts A	
	Swedes	Hay	Swedes	Hay
Abomasal				
Whole	0.36	0.18	0.23	0.17
Precipitate	0.25	0.17	0.16	0.13
Microbial	0.10	0.05	0.05	0.03
Rumen	0.17	0.08	0.07	0.03

between the two diets was not as marked after acid hydrolysis, but the abomasal digesta of wethers ingesting swede still contained higher proportions of organic Sulphur.

The proportions of total ^{35}S assumed to be non-protein organic Sulphurs before acid hydrolysis in the rumen liquor of wethers offered the swede diets was approximately 0.5 of that for the rape or hybrid turnip diets. A similar difference in the proportion (counts B-counts A) existed between the observations for the hay and complete diets, although after acid hydrolysis, these differences were not apparent.

DISCUSSION

The primary objective of this series of observations was to confirm that the ^{35}S technique of Mathers and Miller (1980) was not suitable for measuring microbial production in the rumen of sheep given forage brassica diets by comparing the rumen liquor and abomasal digesta fractions of sheep offered either a brassica or a non-brassica diet. By treating all the samples in the same manner, any difference in proportions of counts in the various digesta fractions were assumed to be associated with true diet differences and not attributed to inadequate use of the technique.

Sodium Sulphite, Sodium Sulphide and Zinc Sulphate were introduced to the supernatant to act as carriers for any labelled inorganic Sulphite, Sulphide or Sulphate that may have been present. In addition the Zinc Sulphate in combination with the Barium Hydroxide would have the added effect of removing any remaining S-containing proteins in the sample. Any ^{35}S in digesta fractions present after these additions has therefore been assumed to be in non-protein, organic Sulphur compounds (counts B). In order to contribute to the errors associated with the ^{35}S technique found in Experiment 1, the non-protein organic Sulphur compounds would

also have to be present in the solution after acid hydrolysis (counts C). If the compounds were hydrolysed to Sulphite or Sulphide they would probably have been lost to the atmosphere during the drying process. Any labelled Sulphate formed would also have been removed as a consequence of the Sulphate carrier being added. The counts fraction should therefore represent ^{35}S in organic Sulphur compounds rather than inorganic Sulphide, Sulphite or Sulphate.

A comparison between non-brassica and brassica diets over all the observations shows that the ^{35}S counts in non-protein organic Sulphur as a proportion of the ^{35}S counts after the initial centrifugation, both before and after acid hydrolysis, was higher in sheep given the brassica diets than the non-brassica diets. The major evidence for this, is the comparison between the swede and hay diets where before acid hydrolysis, the proportions of disintegrations ml^{-1} with the swede diet were approximately double those with the hay diet. This is also evident with the rumen samples in Experiment 2, compared to those obtained from the sheep offered the complete diet. However, as the observations were conducted at different times of year, with different animals and under different conditions, the two sets of observations are not strictly comparable. In addition the difference in the magnitude of the proportions between the first two sets of observations and the third is probably due to factors such as the type of sheep used and the diets offered.

In comparison to the abomasal samples, the proportion of disintegrations ml^{-1} before acid hydrolysis in the rumen samples were lower. This is probably an artefact of the technique rather than a real difference. In the rumen samples, a greater proportion of the ^{35}S present would still be in the infused form than would appear in the

abomasal samples. This would appear in counts A of the rumen samples, thereby giving a lower proportion of counts B/counts A than that of the abomasal samples. The markedly lower proportions of disintegrations ml^{-1} after acid hydrolysis with the rumen samples compared to the abomasal samples is probably a function of the conditions in the abomasum compared to the rumen. The pH in the abomasum is lower than in the rumen and therefore any acid-labile compounds which could survive in the rumen and therefore be present in the rumen samples and would not be present in the abomasal samples, leading to higher proportions of the disintegrations ml^{-1} being present after acid hydrolysis.

In all diets, the proportions of disintegrations ml^{-1} present after acid hydrolysis were higher in the whole than in the precipiate which in turn were higher than in the microbial fraction. This suggests that the non-protein organic Sulphur compounds containing ^{35}S are present in a soluble form in the abomasal digesta. During the initial centrifugation of the whole abomasal digesta to separate the precipitate and supernatant fractions, some of these compounds could have become trapped in the precipitate fraction but most of them would have been discarded with the supernatant. The washing of the microbial fraction at the end of the process would have removed most of the remaining compounds.

The observations made above support the hypothesis that a greater proportion of non-protein organic Sulphur compounds are present in the digesta fractions of brassica diets compared to non-brassica diets. It has not been possible to identify these compounds but it must be assumed that these compounds are likely to be aglucone products of SMCO or glucosinolate hydrolysis in the rumen.

The proportion of disintegrations ml^{-1} that were present after acid hydrolysis in the abomasal samples in Experiment 2 were related to the total number of disintegrations measured in Experiment 1. This showed that approximately 0.13 of the disintegration in the whole fraction, 0.03 in the precipitate and 0.007 in the microbial fraction were due to ^{35}S in non-protein organic Sulphur compounds. These proportions would account for most of the error with overestimates of microbial protein fractions with the ^{35}S technique in Experiment 1.

Appendix Table 2.1.

DM and Ash content of forage brassica components as reported in the literature.

Species	DM (gkg^{-1})	Ash (gkg^{-1}DM)	Reference
Leaf			
cabbage	114	66	Bradshaw and Borzucki (1981)
cabbage	87	54	Partridge et al (1985)
rape	150-165	111-122	Jones (1959a)
rape	101-105	129-148	Fitzgerald (1984)
kale	140-153	103-157	Jones (1959b)
kale	112-113	153-178	Jones (1965)
turnip	127	149	Barry et al (1971)
swede	143	99	Barry et al (1971)
Stem			
rape	200-225	66-79	Jones (1959a)
rape	111-128	113-142	Fitzgerald (1984)
kale	114-207	66-108	Jones (1959b)
kale	103-126	119-133	Jones (1965)
Bulb			
turnip	76	222	Barry et al (1971)
turnip	77-85	81-114	Partridge et al (1985)
swede	120	62	Dodsworth (1956)
swede	96	153	Barry et al (1971)
swede	97	66	Partridge et al (1985)
stubble turnip	62	-	Dover (1980)

Appendix Table 2.2.

N content of forage brassica components reported in the literature.

Species	N ($gkg^{-1}DM$)	Reference
Leaf		
cabbage	34.0	MacDearmid (1978)
cabbage	32.0	Partridge et al (1985)
rape	42.2	Fitzgerald (1985)
rape	22.1-27.7	Jung et al (1986)
kale	30.3	Drew et al (1974)
kale	28.4	Barry and Drew (1978)
kale	27.9	Barry et al (1984a)
kale	26.7-32.3	Barry et al (1984b)
turnip	33.1	Drew et al (1974)
turnip	31.9	Barry and Drew (1978)
turnip	27.5-43.8	Jung et al (1986)
swede	25.9	Drew et al (1974)
swede	26.2	Barry and Drew (1978)
hybrid turnip	27.5-41.8	Jung et al (1986)
Stem		
rape	14.9-18.7	Armstrong (1984)
rape	26.7	Fitzgerald (1985)
kale	11.0-19.6	Drew et al (1974)
kale	9.9-18.2	Barry and Drew (1978)
kale	20.5	Barry et al (1984a)
kale	18.4-20.8	Barry et al (1984b)

Appendix Table 2.2. (Cont'd)

Species	N (gkg^{-1}DM)	Reference
Bulb		
turnip	28.7	Drew et al (1974)
turnip	27.7	Barry and Drew (1978)
turnip	24.5-31.0	Partridge et al (1985)
turnip	17.8-28.3	Jung et al (1986)
swede	28.7	Drew et al (1974)
swede	20.5	Livingstone et al (1977)
swede	27.7	Barry and Drew (1978)
swede	26.0	MacDearmid (1978)
swede	14.2	Partridge et al (1985)
swede	17.4-23.5	Jung et al (1986).

Appendix Table 2.3.

NDF, ADF and ADL content of forage brassicas reported in the literature.

Species	NDF ($gkg^{-1}DM$)	ADF ($gkg^{-1}DM$)	ADL ($gkg^{-1}DM$)	Reference
cabbage	-	168	-	Partridge et al (1985)
hybrid turnip	-	202	-	Koch et al (1985)
kale (whole plant)	254	220	28	Pelletier and Doneker (1973)
kale (whole plant)	190*	143+	39	Barry et al (1982)
kale (whole plant)	177*	131+	32	Barry et al (1984a)
kale (whole plant)	178*	132+	59	Barry and Manley (1985)
kale (whole plant)	170*	121+	51	Barry et al (1985)
turnip (bulb)	-	159	-	Partridge et al (1985)
swede (bulb)	-	124	-	Partridge et al (1985)
swede (bulb)	-	206	-	Livingstone et al (1977)

* derived from the sum of hemicellulose, cellulose and lignin content
\+ derived from the sum of cellulose and lignin content.

Appendix Table 2.4.

Water soluble carbohydrate content of forage brassicas as reported in the literature.

Species	Water soluble carbohydrate content (g kg^{-1} DM)	Reference
cabbage	253	Hara and Sondona (1982)
cabbage	527	Partridge et al (1985)
kale (leaf)	167	Bath and Rook (1965)
kale (whole plant)	255	Bath and Rook (1965)
kale (whole plant)	208	Barry et al (1982)
kale (whole plant)	279	Barry et al (1984a)
kale (whole plant)	241	Barry and Manley (1985)
kale (whole plant)	262	Barry et al (1985)
stubble turnip (whole plant)	380	Dover (1980)
turnip (bulb)	500 - 610	Topps (1981)
turnip (bulb)	418	Partridge et al (1985)
swede (bulb)	321 - 424	McNaughton and Thow (1972)
swede (bulb)	408	Livingstone et al (1977)
swede (bulb)	500 - 630	Topps (1981)
swede (bulb)	652	Partridge et al (1985)

Appendix Table 2.5.

In vivo digestibility of DM and OM of forage brassica components reported in the literature.

		digestibility of DM	digestibility of OM	Reference
leaf				
	rape	-	0.782-0.791	Armstrong (1984)
	kale	-	0.883	Barry *et al* (1984a)
stem				
	rape	-	0.831-0.846	Armstrong (1984)
	kale	-	0.877	Barry *et al* (1984a)
Bulb				
	turnip	-	0.914	Barry *et al* (1971)
	turnip	0.901	-	Drew *et al* (1974)
	swede	-	0.921	Barry *et al* (1971)
	swede	0.915	-	Drew *et al* (1974)

Appendix Table 2.6.

In vitro digestibility of DM and OM of forage brassica components reported in the literature.

Species	digestibility of DM	digestibility of OM	Reference
Leaf			
cabbage	-	0.863-0.902	Bradshaw and Borzucki (1982)
rape	0.801-0.805	-	Fitzgerald (1984)
rape	-	0.805	Armstrong (1984)
rape	0.837	-	Fitzgerald (1985)
rape	0.883	-	Jung *et al* (1986)
kale	-	0.792-0.894	Stephen (1976)
kale	-	0.790-0.799	Julen (1979)
kale	-	0.876-0.926	Bradshaw and Borzucki (1983)
kale	0.821	-	Jung *et al* (1986)
turnip	0.892	-	Jung *et al* (1986)
swede	0.899	-	Jung *et al* (1986)
hybrid turnip	-	0.790-0.799	Young *et al* (1982)
hybrid turnip	0.860-0.929	-	Koch *et al* (1985)
hybrid turnip	0.907	-	Jung *et al* (1986)
Stem			
rape	-	0.790	Armstrong (1984)
rape	0.682-0.720	-	Fitzgerald (1983)
rape	0.774	-	Fitzgerald (1985)
kale		0.486-0.906	Stephen (1976)
kale	0.721-0.764	-	Julen (1979)

Appendix Table 2.6 (cont'd)

Bulb			
turnip	0.745-0.756	-	Bokhari and Horn (1982)
turnip	0.888	-	Jung et al (1986)
swede	0.818	-	Keane (1975)
swede	0.863-0.891	-	Jung et al (1986)

Appendix Table 2.7.

Liveweight and carcase gains ($gday^{-1}$) in lambs grazing forage brassicas reported in the literature.

Species	Liveweight gain ($g\ day^{-1}$)	Carcass gain ($g\ day^{-1}$)	Reference
cabbage	89 - 186	-	Rutherford and Dover (1981)
rape	112 - 147	-	Speedy et al (1980)
rape	71 - 154	-	Young et al (1982)
rape	50 - 98	65-68	Fitzgerald (1983)[1]
rape	49	57	Fitzgerald (1985)
rape	152	71	Fitzgerald and Black (1984)
kale	59.5	-	Barry et al (1971)
kale	60	-	Scott and Barry (1972)
kale	-	77.8	Jagusch et al (1977)
kale	46 - 92	-	McDonald et al (1977)
kale	119 - 148	-	Barry and Drew (1978)
kale	62 - 158	52-109	Barry et al (1981a)
kale	64	45	Barry et al (1982)
kale	112		Barry et al (1983b)
kale	-6.3-147		Barry and Mosley (1985)
kale	108	52	Fitzgerald and Black (1984)
hybrid turnip	-112-120		Young et al (1982)
stubble turnip	143-218		Speedy et al (1980)
turnip	128		Barry et al (1971)
turnip	128-193		Scott and Barry (1972)
turnip	40	-	Slade (1977)
turnip	81-150		Barry and Drew (1978)
swede	156		Barry et al (1971)
swede	156-198		Scott and Barry (1972)
swede	0-152	18-71	Fitzgerald (1977c)
swede	101-143		Barry and Drew (1978)

N.B. gains for rape and kale relate to whole plant, gains for swede and turnip relate to bulb only.

Ap. Table 3.1. Individual data for intake of OM (g day^{-1}) digestibility of OM, intake of N (g day^{-1}) digestibility of N and liveweights (kg) during sub-period 1 and rumen volume (l) and fractional outflow rate at the end of sub-period 2 - Experiment 1.

Sheep	Crop	OMI	OMD	NI	ND	W	Rumen vol.	Fract. out-flow rate
140	CA	498	0.913	14.5	0.846	27.0	4.1	1.48
129	CA	523	0.926	13.7	0.892	32.0	5.4	1.24
128	CA	370	0.894	14.7	0.823	30.0	5.5	0.82
132	CA	626	0.919	17.2	0.860	29.5	4.4	1.44
131	CA	487	0.910	21.9	0.848	33.0	6.5	0.60
142	CA	585	0.906	16.8	0.834	31.0	3.7	1.64
139	HT	763	0.896	11.3	0.839	32.0	7.3	1.56
138	HT	659	0.876	12.7	0.824	30.5	5.7	1.56
136	HT	568	0.904	13.5	0.866	30.0	6.0	1.28
134	HT	733	0.878	14.6	0.814	31.0	4.0	2.17
141	HT	678	0.884	10.9	0.824	30.0	5.3	1.97
135	HT	744	0.850	12.3	0.783	31.5	4.9	2.13
141	STL	536	0.901	11.8	0.848	31.0	3.8	1.96
138	STL	582	0.877	14.0	0.782	30.0	4.8	1.38
132	STL	626	0.868	9.4	0.778	29.5	7.3	1.48
128	STL	491	0.870	*	0.796	27.0	*	*
126	STL	804	0.878	11.2	0.783	30.0	6.2	1.79
135	STL	827	0.866	10.8	0.772	32.0	6.4	1.93
137	STB	*	*	*	*	*	6.4	1.51
134	STB	869	0.927	7.6	0.769	30.0	6.1	1.74
139	STB	661	0.928	7.0	0.778	31.0	7.7	1.18
136	STB	493	0.933	7.7	0.823	27.5	4.3	1.53
140	STB	758	0.918	8.8	0.726	27.5	4.3	1.94
142	STB	708	0.927	13.2	0.789	29.5	5.3	0.98
133	RL	749	0.867	15.9	0.853	30.5	4.2	2.02
131	RL	506	0.901	*	0.885	29.5	*	*
142	RL	658	0.864	12.3	0.831	30.5	4.5	2.25
134	RL	608	0.883	17.9	0.853	31.0	3.0	2.13
137	RL	547	0.862	14.2	0.812	30.5	3.5	2.03
135	RL	857	0.888	19.5	0.850	32.0	3.9	2.13
139	RS	703	0.781	9.4	0.794	36.5	7.8	1.05
126	RS	581	0.755	8.9	0.779	33.0	6.2	1.15
132	RS	480	0.797	8.4	0.786	31.5	5.3	1.18
141	RS	*	*	*	*	*	3.7	1.40
136	RS	568	0.785	8.8	0.728	30.5	9.4	1.45
140	RS	594	0.749	9.7	0.756	30.0	4.8	1.38
129	KL	656	0.907	9.4	0.861	32.5	6.5	2.09
133	KL	486	0.874	20.4	0.839	31.0	2.3	1.99
142	KL	552	0.862	26.6	0.837	33.0	2.4	1.71
139	KL	643	0.893	12.2	0.871	34.5	7.2	1.43
126	KL	357	0.917	16.3	0.894	31.0	3.1	1.34
136	KL	610	0.907	13.5	0.886	30.0	4.0	2.20
132	KS	836	0.894	21.8	0.852	32.0	3.6	1.56
135	KS	892	0.883	23.8	0.859	38.0	3.8	1.45
134	KS	500	0.885	15.6	0.874	31.5	1.9	2.52

Ap. Table 3.1 cont'd

Sheep	Crop	OMI	OMD	NI	ND	W	Rumen volume	Fractional outflow rate
137	KS	602	0.876	13.7	0.850	32.0	2.8	2.29
130	KS	411	0.891	14.2	0.866	30.0	3.3	1.30
141	KS	395	0.883	10.2	0.850	30.0	4.2	1.30
138	SW	764	0.937	14.6	0.804	36.0	5.5	0.98
132	SW	602	0.962	6.2	0.877	38.0	7.2	1.41
141	SW	*	*	*	*	*	9.8	0.71
126	SW	866	0.925	14.5	0.759	35.0	6.0	1.05
131	SW	485	0.947	9.6	0.852	32.0	5.0	1.02
135	SW	846	0.949	11.3	0.831	40.0	5.6	1.35
133	SW	576	0.942	9.5	0.858	34.0	5.4	1.18
140	SW	565	0.937	9.6	0.804	33.0	5.7	1.12

Ap. Table 3.2. Individual data for intake and flow past abomasum of OM (g day^{-1}) intake of N and flow past abomasum of total N and NAN (g day^{-1}), rumen ammonia concentration (mg l^{-1}) total VFA concentration (mmol l^{-1}) and relative proportions of acetate, propionate and butyrate in the rumen during sub-period 1 - Experiment 1.

Day	Sheep	Crop	OMI	OM flow	NI	Total N flow	NAN flow	Rumen NH_3 conc.	Total VFA conc.	Acetate	Prop.	Buty.
1	140	CA	429	175	13.6	13.6	12.6	185.3	36.6	62	24	14
1	129	CA	415	135	12.9	11.4	10.5	187.0	40.6	62	30	08
1	128	CA	280	100	8.6	7.3	6.8	161.5	33.3	61	30	09
1	132	CA	539	162	17.0	13.0	12.3	180.2	42.7	57	34	09
1	131	CA	211	79	5.5	6.3	5.7	128.2	28.0	66	26	08
1	142	CA	455	203	13.3	17.2	16.5	137.7	37.8	63	28	09
1	139	HT	568	220	18.8	20.2	18.9	137.7	46.7	62	32	06
1	133	HT	564	220	17.3	18.5	17.8	129.2	49.5	60	33	07
1	136	HT	467	221	14.3	16.2	15.1	154.7	49.6	62	29	09
1	134	HT	613	231	18.6	16.9	16.2	122.4	51.4	60	31	10
1	141	HT	569	211	17.3	17.0	15.9	137.7	54.8	62	31	08
1	135	HT	603	250	18.4	16.9	16.1	120.7	51.1	59	30	10
1	141	STL	396	133	13.1	9.5	9.1	192.1	71.5	64	24	12
1	138	STL	474	162	15.6	12.6	12.2	137.7	64.0	63	27	10
1	132	STL	552	212	18.2	12.9	12.4	119.0	65.4	62	28	10
1	128	STL	431	119	14.3	9.2	8.7	134.3	59.5	62	30	08
1	126	STL	694	272	22.8	20.6	19.2	173.4	69.2	61	31	08
1	135	STL	690	205	22.8	15.6	14.8	147.9	71.1	61	28	10
1	137	STB	588	147	9.4	12.4	12.1	68.0	57.0	49	43	08
1	134	STB	778	154	12.1	13.1	12.9	40.8	66.2	46	43	11
1	139	STB	627	144	10.1	11.5	11.1	113.9	59.3	50	38	11
1	136	STB	508	149	7.9	10.8	10.6	57.8	55.2	49	44	07
1	140	STB	720	267	11.6	20.9	20.7	30.6	63.1	44	42	14
1	142	STB	706	223	11.5	17.0	16.8	18.7	49.4	43	39	18
1	133	RL	539	193	22.2	14.6	14.1	251.6	69.8	59	31	10
1	142	RL	561	218	20.4	15.4	14.7	265.2	64.1	61	29	10
1	134	RL	461	142	16.9	11.3	10.9	159.8	56.4	63	28	09
1	137	RL	484	179	17.6	12.5	11.9	181.9	55.0	61	27	12
1	135	RL	*	*	*	*	*	168.3	70.6	60	27	13
1	139	RS	587	277	12.6	14.3	13.0	302.6	66.3	58	30	12
1	126	RS	489	222	10.4	7.4	6.8	181.9	60.9	59	31	10
1	132	RS	397	193	8.5	6.9	6.4	277.1	61.2	63	26	12
1	141	RS	403	173	8.6	8.4	7.8	190.4	61.6	59	30	11
1	136	RS	*	*	*	*	*	185.3	64.5	64	23	13
1	140	RS	493	208	10.5	9.7	9.2	164.9	70.2	62	26	12
1	129	KL	533	277	27.8	17.8	16.9	200.6	75.0	67	21	13
1	133	KL	441	146	18.0	11.1	10.7	144.5	55.0	61	27	13
1	142	KL	483	193	19.8	13.8	13.5	151.3	60.7	64	23	13
1	139	KL	576	244	23.6	17.9	17.0	222.7	76.4	66	19	15
1	126	KL	308	101	12.5	7.5	7.0	154.7	58.2	68	22	10
1	136	KL	521	203	21.3	15.2	14.2	141.1	63.0	65	23	13
1	132	KS	723	258	21.8	17.4	17.1	129.2	65.8	61	29	10
1	135	KS	732	260	21.9	16.3	15.7	149.6	82.6	61	30	09
1	134	KS	401	127	12.0	7.5	7.2	207.4	76.6	63	26	12

Ap.Table 3.2. cont'd

Day	Sheep	Crop	OMI	OM Flow	NI	Total N Flow	NAN Flow	Rumen NH_3 conc.	Total VFA conc.	Acetate	Propionate	Butyrate
1	137	KS	526	172	15:8	10.8	10.1	173.4	71.8	63	30	07
1	130	KS	403	167	12.3	8.8	8.5	180.2	67.5	62	29	09
1	141	KS	355	156	10.7	11.5	11.3	163.2	71.1	62	30	08
1	138	SW	582	181	12.2	15.1	14.8	64.6	54.3	52	29	19
1	132	SW	440	172	9.2	14.0	13.6	51.0	43.5	56	33	10
1	141	SW	394	138	8.4	10.3	10.0	91.8	42.1	58	35	07
1	126	SW	676	187	14.3	16.8	16.3	71.4	47.0	52	39	08
1	131	SW	338	131	6.9	6.7	6.5	85.0	41.9	60	31	09
1	135	SW	*	*	*	*	*	76.5	55.2	51	39	10
1	133	SW	445	139	9.3	10.3	10.1	71.4	39.5	56	35	10
1	129	SW	*	*	*	*	*	76.5	38.4	61	23	17
1	140	SW	*	*	*	*	*	56.1	48.1	60	29	11
2	140	CA	431	123	13.7	9.4	9.2	156.4	37.6	60	25	15
2	129	CA	410	145	12.7	10.4	10.2	161.5	41.8	63	30	07
2	128	CA	279	77	8.6	5.2	5.2	188.7	41.7	64	28	09
2	132	CA	545	154	17.4	9.3	9.8	180.2	40.7	54	39	07
2	131	CA	197	73	6.0	5.2	5.2	134.3	31.5	62	26	12
2	142	CA	489	123	15.1	9.7	9.5	139.4	35.5	56	34	11
2	139	HT	597	211	18.1	17.5	17.2	124.1	44.9	70	22	08
2	133	HT	603	210	18.4	16.3	16.2	93.5	64.9	57	36	07
2	136	HT	395	178	13.0	14.8	14.6	93.5	56.9	69	19	12
2	134	HT	*	*	*	*	*	90.1	40.9	58	35	07
2	141	HT	581	225	17.7	17.6	17.4	100.3	69.7	61	31	08
2	135	HT	641	302	19.5	19.4	19.2	100.3	72.2	59	32	10
2	141	STL	393	146	13.2	11.3	10.8	249.9	71.0	63	27	11
2	138	STL	460	145	15.2	10.9	10.5	153.0	67.5	60	30	10
2	132	STL	526	124	18.2	7.7	7.4	202.3	70.7	60	29	11
2	128	STL	*	*	*	*	*	*	62.3	63	27	10
2	126	STL	685	274	22.6	22.0	20.9	183.6	75.9	57	33	10
2	135	STL	664	220	21.9	16.3	15.5	197.2	76.2	60	29	11
2	137	STB	577	108	9.3	8.6	8.4	95.2	53.8	48	41	11
2	134	STB	*	*	*	*	*	51.0	61.5	40	46	13
2	139	STB	605	147	9.8	11.8	11.4	93.5	51.9	48	38	14
2	136	STB	489	146	7.9	11.1	10.8	56.1	56.6	47	41	12
2	140	STB	688	283	11.1	22.2	22.0	25.5	82.0	46	39	14
2	142	STB	624	149	9.8	14.5	14.1	32.3	35.8	51	34	15
2	133	RL	611	222	22.3	16.0	15.6	130.9	59.1	61	30	08
2	142	RL	550	207	20.1	15.2	14.5	170.0	63.6	62	28	10
2	134	RL	445	93	16.4	8.1	7.8	217.6	65.3	64	24	12
2	137	RL	479	184	17.5	12.3	11.7	144.5	55.6	62	29	09
2	135	RL	*	*	*	*	*	149.6	56.5	54	31	14
2	139	RS	*	*	*	*	*	*	68.4	60	29	10
2	126	RS	502	234	10.7	7.2	6.7	187.0	65.0	62	28	09
2	132	RS	392	134	8.4	4.5	4.2	154.7	59.9	65	24	11
2	141	RS	381	180	8.5	6.5	6.1	149.6	61.0	60	31	09

Ap.Table 3.2. cont'd

Day	Sheep	Crop	OMI	OMI Flow	NI	Total N Flow	NAN Flow	Rumen NH_3 conc.	Total VFA conc.	Acetate	Propionate	Butyrate
2	136	RS	*	*	*	*	*	139.4	64.7	65	22	13
2	140	RS	513	287	10.5	9.7	9.3	175.1	67.6	61	29	10
2	129	KL	512	272	20.9	17.4	16.5	255.0	72.5	67	22	11
2	133	KL	423	159	17.3	11.4	10.8	168.3	54.6	66	24	10
2	142	KL	*	*	*	*	*	249.9	52.7	67	22	11
2	139	KL	565	276	23.1	19.9	19.7	221.0	77.2	68	20	12
2	126	KL	310	138	12.7	9.6	9.1	130.9	45.6	68	21	11
2	136	KL	505	206	19.6	16.1	16.9	156.4	57.0	67	22	12
2	132	KS	655	316	19.5	20.3	18.3	158.1	67.7	64	24	11
2	135	KS	782	335	23.0	14.2	14.5	241.4	82.9	68	25	08
2	134	KS	320	127	9.3	7.1	6.8	319.6	77.9	67	22	11
2	137	KS	496	131	14.8	12.0	11.3	200.6	64.8	65	28	07
2	130	KS	376	137	11.3	8.1	7.7	258.4	72.7	68	23	09
2	141	KS	352	182	10.6	11.2	10.8	158.1	54.7	65	26	09
2	138	SW	597	173	12.6	13.8	13.5	76.5	50.8	52	35	12
2	132	SW	454	175	9.6	12.4	12.1	69.7	46.9	54	37	09
2	141	SW	398	143	8.4	11.0	11.7	68.4	43.8	58	35	07
2	126	SW	560	221	12.0	16.1	15.5	98.6	50.0	55	36	09
2	131	SW	347	108	7.2	7.8	7.6	91.8	50.2	57	34	10
2	135	SW	*	*	*	*	*	91.8	57.4	51	42	08
2	133	SW	453	134	9.5	8.8	8.6	73.1	36.2	59	34	07
2	129	SW	*	*	*	*	*	*	*	*:	*:	*
2	140	SW	396	160	8.3	12.2	12.0	57.8	48.5	61	27	12

Ap.Table 4.1. Individual data for intake ($gday^{-1}$) and digestibility of OM and N, digestibility of NDF, loss of N in faeces and urine and liveweights during Sub-period 1 - Experiment 2.

Period	Sheep	Crop	Treatment	Block	OMI	OMD	NDFD	NI	ND	Loss of N in faeces	Loss of N in urine	W
1	76	HT	B	2	478	0.874	0.557	17.5	0.820	3.15	10.0	28.5
1	77	HT	O	1	353	0.897	0.720	14.9	0.890	1.64	8.6	29.5
1	86	HT	O	3	245	0.883	0.608	11.2	0.870	1.46	9.5	27.5
1	91	HT	B	1	539	0.871	0.577	20.3	0.835	3.35	11.2	32.0
1	92	RL	B	2	478	0.862	0.727	16.8	0.847	2.56	9.5	29.0
1	93	HT	O	1	304	0.914	0.657	13.6	0.899	1.38	10.4	28.0
1	94	HT	B	3	*	*	*	*	*	*	*	*
1	95	RL	O	3	185	0.890	0.836	8.5	0.896	0.88	7.6	28.0
1	97	RL	O	1	403	0.877	0.761	17.6	0.873	2.24	10.0	30.0
1	98	RL	B	3	327	0.843	0.638	10.7	0.822	1.91	7.4	29.0
1	99	HT	O	2	333	0.877	0.733	15.2	0.869	1.99	10.3	29.0
1	100	RL	B	1	548	0.885	0.793	19.4	0.865	2.62	12.8	28.0
2	76	HT	O	2	292	0.851	0.600	13.8	0.846	2.13	9.1	27.0
2	77	RL	B	2	491	0.902	0.836	18.8	0.900	1.87	11.3	28.0
2	86	HT	B	3	363	0.862	0.428	12.6	0.814	2.35	9.6	26.0
2	91	HT	O	1	328	0.845	0.499	15.1	0.826	2.70	9.5	30.0
2	92	RL	O	2	358	0.896	0.804	16.9	0.897	1.74	8.1	26.0
2	93	HT	B	1	284	0.761	0.503	8.4	0.651	2.95	5.0	27.0
2	94	HT	O	3	*	*	*	*	*	*	*	*
2	95	RL	B	3	*	*	*	*	*	*	*	*
2	97	RL	B	1	573	0.876	0.751	22.5	0.872	2.88	14.8	29.0
2	98	RL	O	3	*	*	*	*	*	*	*	*
2	99	HT	B	2	345	0.832	0.553	11.3	0.771	2.59	10.8	27.5
2	100	RL	O	1	428	0.880	0.806	20.2	0.885	2.32	10.7	27.0
3	76	RL	O	2	392	0.914	0.818	16.1	0.904	1.54	7.1	25.5
3	77	HT	B	2	510	0.895	0.687	21.1	0.880	2.53	16.6	27.0
3	86	RL	B	3	432	0.898	0.715	14.1	0.862	1.94	8.0	26.0
3	91	RL	O	1	457	0.904	0.797	18.7	0.855	2.71	*	30.0
3	92	HT	O	2	304	0.901	0.672	15.6	0.886	1.78	11.3	26.0
3	93	RL	B	1	516	0.917	0.823	16.5	0.895	1.74	7.3	27.5
3	94	RL	O	3	*	*	*	*	*	*	*	*
3	95	HT	B	3	328	0.914	0.726	12.8	0.892	1.39	4.4	26.0
3	97	HT	B	1	581	0.890	0.642	24.8	0.862	3.41	13.5	29.5
3	98	HT	O	3	*	*	*	*	*	*	*	*
3	99	RL	B	2	508	0.895	0.762	17.4	0.829	2.98	7.3	26.0
3	100	HT	O	1	423	0.857	0.559	21.9	0.865	2.96	13.1	27.5

Ap.Table 4.2. Individual data for intake of DM and N ($gday^{-1}$) flow at abomasum of DM, total N and NAN ($gday^{-1}$) and mean rumen ammonia concentration (mgl^{-1}) for Sub-period 2 - Experiment 2.

Period	Day	Sheep	Crop	Treat.	Block	OMI	OMF	NI	Total N Flow	NAN Flow	Rumen NH3 conc.
1	1	76	HT	B	2	386	149	12.7	10.3	9.7	134
1	1	77	RL	O	2	339	135	13.6	11.6	10.9	127
1	1	86	HT	O	3	229	191	9.9	6.8	6.0	163
1	1	91	HT	B	1	502	218	18.2	14.8	14.1	134
1	1	92	RL	B	2	*	*	*	*	*	*
1	1	93	HT	O	1	317	155	13.9	10.8	10.5	192
1	1	94	HT	B	3	*	*	*	*	*	*
1	1	95	RL	O	3	237	156	9.6	9.4	9.1	87
1	1	97	RL	O	1	375	189	15.1	10.9	10.5	146
1	1	98	RL	B	3	*	*	*	*	*	*
1	1	99	HT	O	2	316	127	13.7	9.8	9.1	145
1	1	100	RL	B	1	548	201	18.4	11.8	11.2	100
2	1	76	HT	O	2	341	202	15.6	9.5	8.7	312
2	1	77	RL	B	2	433	148	16.0	7.8	7.3	217
2	1	86	HT	B	3	407	157	14.3	8.8	8.2	255
2	1	91	HT	O	1	415	260	19.0	11.5	11.0	293
2	1	92	RL	O	2	340	123	16.0	7.7	7.1	266
2	1	93	HT	B	1	485	208	18.0	11.8	10.8	247
2	1	94	HT	O	3	*	*	*	*	*	*
2	1	95	RL	B	3	324	140	11.5	7.1	6.1	174
2	1	97	RL	B	1	551	175	20.7	9.9	9.2	289
2	1	98	RL	O	3	180	70	8.9	3.8	3.0	235
2	1	99	HT	B	2	*	*	*	*	*	*
2	1	100	RL	O	1	406	143	19.2	9.3	8.7	243
3	1	76	RL	O	2	370	109	16.5	7.0	6.6	421
3	1	77	HT	B	2	*	*	*	*	*	*
3	1	86	RL	B	3	416	129	14.4	7.2	5.9	328
3	1	91	RL	O	1	317	129	13.7	7.1	6.5	315
3	1	92	HT	O	2	*	*	*	*	*	*
3	1	93	RL	B	1	263	117	7.1	6.8	6.2	219
3	1	94	RL	B	3	*	*	*	*	*	*
3	1	95	HT	B	3	*	*	*	*	*	*
3	1	97	HT	B	1	561	175	23.1	11.8	11.2	373
3	1	98	HT	O	3	*	*	*	*	*	*
3	1	99	RL	B	2	*	*	*	*	*	*
3	1	100	HT	O	1	443	130	22.8	12.5	11.1	271
1	2	76	HT	B	2	411	185	13.8	12.7	11.8	151
1	2	77	RL	O	2	339	111	13.5	7.4	6.6	182
1	2	86	HT	O	3	221	151	9.5	6.5	6.2	172
1	2	91	HT	B	1	491	312	17.3	22.3	21.1	174
1	2	92	RL	B	2	*	*	*	*	*	*
1	2	93	HT	O	1	282	133	12.4	11.2	10.3	240
1	2	94	HT	B	3	*	*	*	*	*	*
1	2	95	RL	O	3	199	105	8.7	6.9	6.3	152
1	2	97	RL	O	1	387	147	15.6	8.8	8.3	171

Ap.Table 4.2. cont'd

Period	Day	Sheep	Crop	Treatment	Block	OMI	OM flow	NI	Total N flow	NAN Flow	Rumen NH_3 conc.
1	2	98	RL	B	3	*	*	*	*	*	*
1	2	99	HT	O	2	301	111	13.1	7.7	6.0	173
1	2	100	RL	B	1	550	180	18.5	10.9	10.0	170
2	2	76	HT	O	2	343	190	15.7	6.2	5.6	265
2	2	77	RL	B	2	377	148	13.6	6.3	5.8	243
2	2	86	HT	B	3	401	166	14.0	9.7	9.0	306
2	2	91	HT	O	1	388	253	17.7	13.3	12.2	285
2	2	92	RL	O	2	353	136	16.7	8.0	7.6	332
2	2	93	HT	B	1	472	245	17.4	16.5	15.5	260
2	2	94	HT	O	3	*	*	*	*	*	*
2	2	95	RL	B	3	349	128	12.6	7.4	6.7	245
2	2	97	RL	B	1	567	184	20.8	10.1	9.5	409
2	2	98	RL	O	3	176	68	8.8	3.4	3.2	209
2	2	99	HT	B	2	*	*	*	*	*	*
2	2	100	RL	O	1	422	174	19.9	11.2	10.7	235
3	2	76	RL	O	2	359	160	16.5	12.5	11.1	291
3	2	77	HT	B	2	454	169	18.2	25.3	19.9	235
3	2	86	RL	B	3	411	87	14.3	8.6	7.2	303
3	2	91	RL	O	1	264	94	10.9	7.4	7.0	258
3	2	92	HT	O	2	*	*	*	*	*	*
3	2	93	RL	B	1	*	*	*	*	*	*
3	2	94	RL	B	3	*	*	*	*	*	*
3	2	95	HT	B	3	*	*	*	*	*	*
3	2	97	HT	B	1	558	222	22.9	24.3	22.0	251
3	2	98	HT	O	3	*	*	*	*	*	*
3	2	99	RL	B	2	*	*	*	*	*	*
3	2	100	HT	O	1	466	132	23.2	10.0	9.4	211

Ap.Table 4.3. Individual total VFA concentrations ($mmoll^{-1}$) in rumen and relative proportions of acetate, propionate and butyrate during sub-period 2 - Experiment 2 (samples from day 1 and day 2 were combined prior to analysis).

Period	Sheep	Crop	Treatment	Block	Total VFA conc.	Acetate : Propionate : Butyrate
1	76	RL	B	2	45.92	66:23:11
1	77	HT	0	2	53.47	66:24:11
1	86	RL	0	3	44.25	69:17:14
1	91	RL	B	1	61.13	68:16:16
1	93	RL	0	1	54.88	70:16:14
1	95	HT	0	3	47.53	65:19:16
1	97	HT	0	1	51.42	68:21:10
1	99	RL	0	2	49.30	68:18:14
1	100	HT	B	1	64.92	61:25:15
2	76	RL	0	2	57.70	71:18:11
2	77	HT	B	2	61.30	66:20:14
2	86	RL	B	3	55.63	63:22:15
2	91	RL	0	1	54.91	69:19:12
2	92	HT	0	2	55.84	65:25:11
2	93	RL	B	1	60.15	63:21:15
2	95	HT	B	3	47.00	64:20:15
2	97	HT	B	1	69.69	61:23:17
2	98	HT	0	3	41.74	74:19:08
2	100	HT	0	1	59.82	67:19:13
3	76	HT	0	2	56.45	66:21:13
3	77	RL	B	2	57.04	65:20:14
3	86	HT	B	3	65.55	64:22:13
3	91	HT	0	1	43.55	65:22:13
3	93	HT	B	1	40.29	65:22:13
3	97	RL	B	1	69.97	69:18:13
3	100	RL	0	1	47.27	71:18:11

Ap.Table 5.1. Individual data for OM intake of supplement forage, forage DOM intake ($gday^{-1}$) and liveweight (kg) during period 1 and 2 with lambs grazing hybrid turnip - Experiment 3

Sheep	Treatment	Period	Supp. Intake	Forage Intake	DOM Intake	W	Period	Supp. Intake	Forage Intake	DOM Intake	W
1	ZERO	1	0	654	564	31.5	2	0	1116	945	32.0
2	ZERO	1	0	631	544	32.0	2	0	793	672	32.0
3	ZERO	1	0	714	615	30.0	2	0	889	753	30.0
4	ZERO	1	0	620	534	29.5	2	0	565	479	29.0
5	ZERO	1	*	*	*	31.0	2	0	787	667	29.0
6	ZERO	1	0	1014	874	28.0	2	0	759	643	26.0
7	ZERO	1	0	564	486	30.0	2	0	973	824	29.0
8	ZERO	1	*	*	*	*	2	*	*	*	*
1	BAR	1	138	841	842	30.0	2	116	788	766	29.0
2	BAR	1	138	741	756	30.0	2	138	864	849	30.0
3	BAR	1	134	710	726	29.5	2	91	963	893	29.5
4	BAR	1	138	943	930	32.0	2	136	921	896	29.0
5	BAR	1	138	620	652	31.5	2	124	599	613	30.0
6	BAR	1	138	695	716	27.0	2	29	679	600	26.0
7	BAR	1	138	675	699	29.5	2	111	731	714	26.5
8	BAR	1	138	1274	1215	29.0	2	130	459	499	30.0
1	BAR_S	1	138	519	565	29.0	2	138	683	696	30.0
2	BAR_S	1	138	662	688	31.0	2	111	729	712	27.5
3	BAR_S	1	136	619	649	28.5	2	57	683	627	28.5
4	BAR_S	1	138	686	709	24.0	2	0	843	714	28.0
5	BAR_S	1	138	449	504	27.5	2	130	613	630	28.0
6	BAR_S	1	138	1016	993	36.0	2	104	1231	1131	33.5
7	BAR_S	1	138	622	653	30.0	2	130	623	638	28.5
8	BAR_S	1	138	681	704	30.5	2	130	923	892	29.5
1	SB	1	0	891	768	31.5	2	0	859	728	31.5
2	SB	1	0	671	578	29.0	2	0	676	573	28.0
3	SB	1	64	873	807	32.5	2	0	763	646	33.0
4	SB	1	17	622	551	27.5	2	0	631	534	27.0
5	SB	1	8	857	746	25.0	2	0	671	568	24.0
6	SB	1	110	686	685	30.5	2	0	907	768	28.5
7	SB	1	6	648	562	30.0	2	0	1096	928	28.0
8	SB	1	38	663	604	32.0	2	0	857	726	31.0

Ap.Table 5.2. Individual data for liveweight (kg) OM intake of supplement, forage and forage DOM intake ($gday^{-1}$) estimated using method A and method B, during period 1 and period 2 with lamb grazing rape leaf - Experiment 3.

Period	Treatment	Sheep	Supp. Intake	Forage Intake	DOM Intake	Forage Intake	DOM Intake	W
1	ZERO	1	0	1068	662	889	551	25.0
1	ZERO	2	0	650	861	541	717	30.0
1	ZERO	3	0	525	963	437	801	27.0
1	ZERO	4	0	604	1228	503	1022	30.5
1	ZERO	5	0	1035	1209	861	1006	33.0
1	ZERO	6	0	658	1031	547	858	29.5
1	ZERO	7	0	1707	944	1420	785	26.5
1	ZERO	8	0	714	990	594	823	29.0
1	BAR	1	87	745	772	694	716	30.5
1	BAR	2	128	1030	963	966	910	30.0
1	BAR	3	121	899	802	851	770	25.0
1	BAR	4	138	1039	945	982	903	31.0
1	BAR	5	111	928	970	866	902	29.5
1	BAR	6	138	718	851	715	825	29.5
1	BAR	7	13	612	926	520	781	31.0
1	BAR	8	125	1585	1258	1425	1153	30.5
1	BAR_S	1	115	917	895	861	842	28.0
1	BAR_S	2	124	886	978	843	919	30.0
1	BAR_S	3	138	856	781	829	767	27.0
1	BAR_S	4	135	850	971	822	923	32.0
1	BAR_S	5	116	697	1258	679	1145	27.0
1	BAR_S	6	36	893	1055	774	909	26.5
1	BAR_S	7	138	635	776	646	763	31.0
1	BAR_S	8	76	793	1181	724	1047	32.0
1	SB	1	0	658	1105	547	919	28.5
1	SB	2	2	1146	1184	955	987	30.5
1	SB	3	34	569	768	502	668	29.5
1	SB	4	2	1041	1058	868	882	33.0
1	SB	5	0	879	1237	731	1029	28.5
1	SB	6	1	594	105	495	88	28.5
1	SB	7	134	668	813	695	791	29.0
1	SB	8	12	771	959	652	803	28.0

Ap.Table 5.2. cont'd

Period	Treatment	Sheep	Supp. intake	Forage Intake	DOM Intake	Forage Intake	DOM Intake	W
2	ZERO	1	0	1005	969	855	825	27.0
2	ZERO	2	0	1030	1000	877	851	29.5
2	ZERO	3	0	1222	1322	1040	1125	26.5
2	ZERO	4	0	670	1036	570	881	30.5
2	ZERO	5	0	1130	1274	962	1084	36.5
2	ZERO	6	0	551	796	469	678	30.0
2	ZERO	7	0	799	870	680	741	28.5
2	ZERO	8	*	*	*	*	*	30.0
2	BAR	1	134	1119	1254	1066	1181	32.5
2	BAR	2	139	543	181	579	271	31.0
2	BAR	3	138	909	1020	891	986	27.0
2	BAR	4	128	644	1186	657	1118	36.5
2	BAR	5	111	756	1153	738	1076	31.5
2	BAR	6	130	523	948	556	917	32.0
2	BAR	7	74	671	1252	634	1129	33.5
2	BAR	8	129	557	924	584	896	32.0
2	BAR_S	1	138	1189	1175	1129	1118	29.0
2	BAR_S	2	138	917	1199	898	1137	31.5
2	BAR_S	3	136	672	998	687	965	30.0
2	BAR_S	4	130	925	1124	898	1067	33.5
2	BAR_S	5	138	647	986	668	957	31.5
2	BAR_S	6	138	755	1008	760	975	29.5
2	BAR_S	7	138	708	907	720	889	30.5
2	BAR_S	8	138	755	859	760	848	36.5
2	SB	1	53	790	1274	717	1129	31.0
2	SB	2	123	1303	1016	1213	969	33.0
2	SB	3	115	450	984	481	935	31.0
2	SB	4	10	1096	1564	941	1340	36.0
2	SB	5	111	741	1589	725	1446	31.0
2	SB	6	97	1105	1003	1023	936	31.0
2	SB	7	130	810	963	800	922	32.5
2	SB	8	20	723	936	632	814	29.0

Ap.Table 5.3. Individual data for liveweight at slaughter, weight of carcase, carcase muscle, fat, crude protein and chemical fat, total crude protein and total chemical fat (kg) in lambs grazing either hybrid turnip or rape lead - Experiment 3.

Sheep	Crop	Treat.	W	Carcase wt.	Carcase muscle	Carcase fat	Carcase CP	Carcase Chem. Fat	Total CP	Total Chem. Fat
449	HT	BAR	32.5	15.1	8.40	2.47	2.45	2.07	4.03	4.16
401	HT	BAR_S	34.5	16.3	8.90	4.34	2.85	3.33	4.66	5.22
446	HT	BAR_S	40.0	19.5	10.74	5.64	3.21	4.77	4.96	6.80
447	HT	BAR	36.5	17.6	8.85	4.89	2.93	4.14	4.80	5.94
491	HT	SB	28.5	12.7	7.18	2.80	2.29	2.06	3.85	3.20
407	HT	BAR	35.5	16.2	8.78	4.21	2.86	3.30	4.59	5.22
416	HT	BAR	34.5	16.8	8.53	4.60	2.60	3.68	4.33	5.05
433	HT	BAR	34.5	16.7	8.63	4.39	2.67	3.54	4.26	5.02
497	HT	BAR_S	37.0	16.7	9.12	4.50	2.59	3.41	4.35	5.02
432	HT	BAR_S	32.5	13.9	7.72	3.14	2.25	2.25	3.79	3.54
507	HT	ZERO	33.0	15.0	7.96	3.15	2.41	2.20	4.06	3.49
466	HT	BAR_S	35.0	16.7	8.02	4.85	2.49	3.77	4.18	5.90
510	HT	SB	35.0	16.4	8.22	4.30	2.65	3.47	4.40	5.28
442	HT	ZERO	37.0	17.5	8.40	5.12	2.78	3.96	4.62	5.80
436	HT	BAR	37.5	16.6	8.02	4.18	2.83	3.26	4.56	5.18
498	HT	ZERO	36.0	16.6	9.24	4.17	2.44	3.34	4.21	5.18
410	HT	BAR_S	35.0	17.6	11.07	5.02	3.19	3.73	4.83	5.36
503	HT	ZERO	31.5	14.2	7.00	3.75	2.19	2.86	3.71	4.56
414	HT	ZERO	35.5	16.5	8.22	4.02	2.57	3.33	4.29	4.87
461	HT	SB	31.5	14.5	6.82	4.12	2.17	3.20	3.71	5.03
499	HT	SB	34.5	16.7	8.04	4.92	2.45	3.43	4.35	5.69
420	HT	SB	36.5	17.1	8.22	5.86	2.43	4.70	3.99	7.04
454	HT	SB	36.5	17.7	8.96	4.67	2.86	4.00	4.62	5.64
487	HT	ZERO	35.0	15.3	7.87	3.66	2.30	2.78	3.97	4.40
457	RL	BAR_S	37.0	15.3	7.43	3.37	2.48	2.82	4.22	4.74
470	RL	ZERO	42.5	20.0	8.48	7.03	2.87	5.74	4.72	8.87
450	RL	SB	35.0	17.3	8.01	5.14	2.74	3.58	4.35	5.35
484	RL	SB	40.0	17.1	7.91	5.13	2.65	3.97	4.60	6.08
512	RL	BAR	38.0	16.5	7.89	4.93	2.74	3.60	4.55	5.36
480	RL	BAR_S	37.0	16.7	7.49	5.20	2.64	4.03	4.34	6.34
428	RL	SB	36.0	16.5	8.46	4.20	2.64	3.42	4.29	5.57
463	RL	BAR	35.0	15.1	7.60	3.66	2.53	2.60	4.16	4.17
460	RL	SB	36.0	18.0	8.96	4.93	3.12	4.18	4.87	5.80
422	RL	ZERO	34.5	16.6	8.17	4.51	2.85	3.69	4.42	5.86
477	RL	BAR	37.5	16.9	8.12	4.43	2.74	3.21	4.55	5.20
431	RL	SB	36.0	16.4	8.13	4.18	2.54	3.62	4.11	5.38
406	RL	BAR	36.5	17.3	7.43	6.31	2.36	5.33	4.14	7.66
424	RL	BAR_S	37.0	17.6	8.26	5.54	2.63	4.49	4.33	6.80
455	RL	BAR_S	40.0	18.8	8.26	6.12	2.60	4.89	4.43	7.04
429	RL	BAR	36.5	17.0	8.64	4.53	2.79	3.36	4.47	5.41
444	RL	SB	43.5	20.0	9.01	6.71	3.03	5.30	5.04	7.60
418	RL	BAR_S	38.0	16.1	7.91	3.61	2.66	3.14	4.50	4.91
472	RL	ZERO	36.0	17.7	8.54	4.93	2.51	4.14	4.12	6.19
496	RL	ZERO	41.0	16.7	8.60	4.32	2.91	3.15	4.80	5.17
471	RL	BAR	41.5	19.0	8.24	6.40	2.79	4.95	4.68	6.95
493	RL	ZERO	35.0	16.0	7.91	4.87	2.71	3.88	4.22	6.42
405	RL	ZERO	34.0	14.4	8.27	3.25	2.49	2.32	3.36	3.68
464	RL	BAR_S	35.0	16.8	7.61	5.36	2.65	4.69	4.28	6.69

Ap.Table 6.1. Individual data for intake of supplement and forage ($gday^{-1}$) and liveweight (kg) for lambs grazing rape stem - Experiment 4

Treatment	Sheep	Supplement intake	Forage intake	W
ZERO	1	0	659	28.5
ZERO	2	0	787	28.5
ZERO	3	0	654	30.5
ZERO	4	0	855	30.0
ZERO	5	0	672	26.5
ZERO	6	0	662	34.0
ZERO	7	0	466	27.0
ZERO	8	0	658	34.0
BAR	1	138	618	29.0
BAR	2	138	621	28.0
BAR	3	138	758	32.0
BAR	4	138	683	29.0
BAR	5	138	706	28.5
BAR	6	138	554	29.5
BAR	7	138	528	30.0
BAR	8	136	446	27.0
BAR_S	1	138	516	30.0
BAR_S	2	138	494	30.0
BAR_S	3	138	486	32.0
BAR_S	4	138	698	28.0
BAR_S	5	123	582	27.0
BAR_S	6	138	959	31.5
BAR_S	7	138	810	28.5
BAR_S	8	138	730	30.5
SB_S	1	81	817	30.0
SB_S	2	138	371	29.0
SB_S	3	138	757	31.5
SB_S	4	138	614	33.5
SB_S	5	138	596	34.0
SB_S	6	138	547	26.5
SB_S	7	138	821	31.5
SB_S	8	138	406	29.0

Ap.Table 7.1. Individual data for intake of OM ($gday^{-1}$) and liveweight (kg) over six periods - Experiment 5

Period	Sheep	Treatment	Block	OMI	W	Period	Sheep	Treatment	Block	OMI	W
1	1	PAN	5	833	32.5	2	16	BLO	2	917	29.0
1	2	CON	4	798	33.5	2	17	PAN	4	890	30.0
1	3	CON	1	818	30.5	2	18	CON	3	867	30.0
1	4	PAN	1	889	31.5	2	19	PAN	7	932	30.0
1	5	BLO	4	775	29.0	2	20	PAN	9	*	28.5
1	6	CON	6	*	29.5	2	21	BLO	10	568	32.5
1	7	CON	2	959	33.5	2	22	CON	9	578	31.0
1	8	PAN	3	872	30.0	2	23	BLO	8	625	34.5
1	9	BLO	5	629	32.0	2	24	BLO	9	703	24.0
1	10	BLO	3	900	29.5	2	25	CON	10	513	31.0
1	11	BLO	1	957	29.5	2	26	CON	7	825	33.5
1	12	CON	5	919	33.5	2	27	PAN	8	625	29.5
1	13	PAN	2	780	30.0	2	28	BLO	7	999	32.5
1	14	BLO	6	744	28.0	2	29	PAN	10	727	31.0
1	15	PAN	6	658	24.0	2	30	CON	8	*	34.0
1	16	BLO	2	957	29.0	3	1	PAN	5	823	32.5
1	17	PAN	4	854	30.0	3	2	CON	4	871	32.0
1	18	CON	3	821	30.0	3	3	CON	1	797	33.0
1	19	PAN	7	841	30.0	3	4	PAN	1	902	34.5
1	20	PAN	9	*	28.5	3	5	BLO	4	750	32.0
1	21	BLO	10	492	32.5	3	6	CON	6	*	28.0
1	22	CON	9	598	31.0	3	7	CON	2	956	36.5
1	23	BLO	8	670	34.5	3	8	PAN	3	792	35.0
1	24	BLO	9	660	24.0	3	9	BLO	5	638	33.0
1	25	CON	10	545	31.0	3	10	BLO	3	661	32.0
1	26	CON	7	869	33.5	3	11	BLO	1	866	32.5
1	27	PAN	8	711	29.5	3	12	CON	5	934	33.5
1	28	BLO	7	915	32.5	3	13	PAN	2	691	31.0
1	29	PAN	10	729	31.0	3	14	BLO	6	619	30.0
1	30	CON	8	702	34.0	3	15	PAN	6	669	27.5
2	1	PAN	5	778	32.5	3	16	BLO	2	877	34.0
2	2	CON	4	845	33.5	3	17	PAN	4	676	32.5
2	3	CON	1	749	30.5	3	18	CON	3	871	33.0
2	4	PAN	1	933	31.5	3	19	PAN	7	856	34.5
2	5	BLO	4	738	29.0	3	20	PAN	9	*	26.5
2	6	CON	6	*	29.5	3	21	BLO	10	705	33.0
2	7	CON	2	1057	33.5	3	22	CON	9	696	33.5
2	8	PAN	3	831	30.0	3	23	BLO	8	802	36.0
2	9	BLO	5	589	32.0	3	24	BLO	9	620	26.0
2	10	BLO	3	736	29.5	3	25	CON	10	671	30.5
2	11	BLO	1	870	29.5	3	26	CON	7	761	36.0
2	12	CON	5	969	33.5	3	27	PAN	8	761	30.0
2	13	PAN	2	670	30.0	3	28	BLO	7	1146	37.5
2	14	BLO	6	653	28.0	3	29	PAN	10	718	33.0
2	15	PAN	6	687	24.0	3	30	CON	8	*	34.5

Ap.Table 7.1. cont'd

Period	Sheep	Treatment	Block	OM intake	W
4	1	PAN	5	608	32.5
4	2	CON	4	823	32.0
4	3	CON	1	809	33.0
4	4	PAN	1	977	34.5
4	5	BLO	4	744	32.0
4	6	CON	6	*	28.0
4	7	CON	2	865	36.5
4	8	PAN	3	762	35.0
4	9	BLO	5	539	33.0
4	10	BLO	3	808	32.0
4	11	BLO	1	887	32.5
4	12	CON	5	868	33.5
4	13	PAN	2	721	31.0
4	14	BLO	6	627	30.0
4	15	PAN	6	695	27.5
4	16	BLO	2	786	34.0
4	17	PAN	4	834	32.5
4	18	CON	3	708	33.0
4	19	PAN	7	862	34.5
4	20	PAN	9	*	26.5
4	21	BLO	10	766	33.0
4	22	CON	9	720	33.5
4	23	BLO	8	840	36.0
4	24	BLO	9	621	25.0
4	25	CON	10	650	30.5
4	26	CON	7	703	36.0
4	27	PAN	8	727	30.0
4	28	BLO	7	1233	37.5
4	29	PAN	10	776	33.0
4	30	CON	8	703	34.5
5	1	PAN	5	539	32.5
5	2	CON	4	851	32.5
5	3	CON	1	815	35.0
5	4	PAN	1	901	36.5
5	5	BLO	4	749	32.5
5	6	CON	6	*	28.5
5	7	CON	2	930	37.5
5	8	PAN	3	779	35.5
5	9	BLO	5	513	33.0
5	10	BLO	3	696	32.0
5	11	BLO	1	898	33.5
5	12	CON	5	887	34.5
5	13	PAN	2	685	32.5
5	14	BLO	6	543	30.0
5	15	PAN	6	660	28.5
5	16	BLO	2	848	34.5
5	17	PAN	4	842	34.0
5	18	CON	3	789	33.0
5	19	PAN	7	951	37.0
5	20	PAN	9	*	25.5
5	21	BLO	10	796	34.0
5	22	CON	9	698	34.0
5	23	BLO	8	811	37.0
5	24	BLO	9	606	28.0
5	25	CON	10	667	32.0
5	26	CON	7	680	35.0
5	27	PAN	8	765	31.5
5	28	BLO	7	1075	39.0
5	29	PAN	10	733	34.0
5	30	CON	8	771	36.0
6	1	PAN	5	447	34.0
6	2	CON	4	750	34.0
6	3	CON	1	747	35.0
6	4	PAN	1	857	36.0
6	5	BLO	4	639	33.0
6	6	CON	6	*	28.5
6	7	CON	2	908	38.5
6	8	PAN	3	758	36.0
6	9	BLO	5	627	34.0
6	10	BLO	3	714	33.5
6	11	BLO	1	845	33.5
6	12	CON	5	852	34.0
6	13	PAN	2	616	32.5
6	14	BLO	6	482	30.5
6	15	PAN	6	597	28.5
6	16	BLO	2	821	35.0
6	17	PAN	4	757	35.0
6	18	CON	3	753	34.0
6	19	PAN	7	817	37.0
6	20	PAN	9	*	25.5
6	21	BLO	10	791	34.0
6	22	CON	9	677	34.0
6	23	BLO	8	713	37.0
6	24	BLO	9	562	28.0
6	25	CON	10	612	32.0
6	26	CON	7	665	35.0
6	27	PAN	8	655	31.5
6	28	BLO	7	988	39.0
6	29	PAN	10	636	34.0
6	30	CON	8	660	36.0

Ap.Table 7.2. Individual data for amount of foam released from rumen (g), proportion of foam that is solid matter and liquid fractional outflow rate from rumen over five periods - Experiment 5

Period	Sheep	Treatment	Block	Foam weight	Prop. solid matter	Fractional outflow rate	Period	Sheep	Treatment	Block	Foam weight	Prop. solid matter	Fractional outflow rate
1	19	PAN	7	260	0.620	0.171	3	25	CON	10	595	0.690	0.128
1	20	PAN	9	*	*	*	3	26	CON	7	495	0.720	0.167
1	21	BLO	10	0	*	0.168	3	27	PAN	8	421	0.620	0.211
1	22	CON	9	268	0.800	0.188	3	28	BLO	7	0	*	0.144
1	23	BLO	8	0	*	0.163	3	29	PAN	10	311	0.640	0.170
1	24	BLO	9	332	0.890	0.168	3	30	CON	8	555	0.890	0.162
1	25	CON	10	35	0.650	0.134	4	19	PAN	7	68	0.730	0.151
1	26	CON	7	250	0.630	0.142	4	20	PAN	9	*	*	*
1	27	PAN	8	305	0.730	0.221	4	21	BLO	10	0	*	0.139
1	28	BLO	7	0	*	0.171	4	22	CON	9	147	0.650	0.179
1	29	PAN	10	28	0.680	0.206	4	23	BLO	8	310	0.860	0.146
1	30	CON	8	343	0.570	0.152	4	24	BLO	9	0	*	0.200
2	19	PAN	7	219	0.280	*	4	25	CON	10	402	0.400	0.131
2	20	PAN	9	*	*	*	4	26	CON	7	343	0.760	0.198
2	21	BLO	10	451	0.540	0.124	4	27	PAN	8	0	*	0.145
2	22	CON	9	360	0.520	0.155	4	28	BLO	7	93	0.490	0.148
2	23	BLO	8	130	0.600	0.119	4	29	PAN	10	143	0.710	0.215
2	24	BLO	9	115	0.300	0.100	4	30	CON	8	137	0.560	0.226
2	25	CON	10	90	0.490	0.149	5	19	PAN	7	0	*	0.199
2	26	CON	7	98	0.470	0.155	5	20	PAN	9	*	*	*
2	27	PAN	8	193	0.620	0.181	5	21	BLO	10	0	*	0.165
2	28	BLO	7	0	*	0.171	5	22	CON	9	156	0.680	0.140
2	29	PAN	10	87	0.400	0.114	5	23	BLO	8	0	*	0.157
2	30	CON	8	0	*	0.188	5	24	BLO	9	55	0.750	0.154
3	19	PAN	7	75	0.310	0.197	5	25	CON	10	128	0.510	0.139
3	20	PAN	9	*	*	*	5	26	CON	7	113	0.730	0.162
3	21	BLO	10	0	*	0.140	5	27	PAN	8	487	0.680	0.136
3	22	CON	9	335	0.660	0.199	5	28	BLO	7	0	*	*
3	23	BLO	8	105	0.760	0.144	5	29	PAN	10	137	0.630	0.151
3	24	BLO	9	140	0.560	0.111	5	30	CON	8	311	0.750	0.151

Ap.Table 8.1. Individual data for OM intake ($gday^{-1}$) and concentration of T_3 and T_4 (μgl^{-1}) in lambs given 0(1), low(2), or high(3) treatment levels of isothiocyanate - Experiment 6

Period	Sheep Block	Treatment	OMI	T_3 Week 1	T_3 Week 2	T_3 Week 3	T_4 Week 1	T_4 Week 2	T_4 Week 3
1	2 3	2	697	0.68	0.78	1.57	46	57	60
1	2 2	2	1034	1.14	0.87	1.42	63	57	47
1	3 1	3	1212	1.75	0.93	1.25	87	98	101
1	3 2	3	856	2.01	1.22	2.70	64	117	164
1	1 2	1	1331	1.61	0.96	1.69	50	49	78
1	2 1	2	1451	1.40	1.30	1.69	51	60	83
1	3 3	3	841	1.78	1.34	1.94	42	143	151
1	1 3	1	971	1.66	0.70	1.55	39	61	91
1	1 1	1	1281	1.05	0.94	1.71	49	63	62
2	2 3	1	748	1.23	1.09	1.03	50	32	46
2	2 2	3	1084	2.04	2.08	1.07	76	46	74
2	3 1	2	1020	1.99	1.25	2.16	79	68	89
2	3 2	1	866	2.02	*	2.62	142	161	151
2	1 2	2	1277	2.38	2.08	1.64	48	62	52
2	2 1	1	1321	1.41	1.20	1.94	71	78	84
2	3 3	2	816	2.24	2.26	1.66	159	127	*
2	1 3	3	575	1.59	1.60	1.46	83	63	70
2	1 1	3	1303	2.02	2.15	2.05	66	86	77
3	2 3	3	1063	1.64	1.18	1.05	46	63	56
3	2 2	1	990	1.03	1.43	1.88	74	83	86
3	3 1	1	957	1.07	2.33	2.08	89	109	117
3	3 2	2	1037	2.16	2.13	1.92	151	130	94
3	1 2	3	559	2.62	1.06	*	52	48	56
3	2 1	3	1306	1.64	1.59	2.30	84	82	104
3	3 3	1	972	1.94	1.60	2.22	*	124	128
3	1 3	2	466	1.66	1.05	1.00	70	50	50
3	1 1	2	1248	1.46	1.94	*	77	81	78

Ap.Table 8.2. Individual data for OM intake ($gday^{-1}$) and concentration of T_3 and T_4 (μgl^{-1}) in lambs given 0 (1), low(2) or high(3) treatment levels of nitrile - Experiment 6

Period	Sheep	Block	Treatment	OMI	T_3 Week 1	T_3 Week2	T_3 Week 3	T_4 Week 1	T_4 Week 2	T_4 Week 3
1	2	1	2	1406	1.81	1.05	2.38	45	63	105
1	2	3	2	1171	1.36	0.97	2.08	39	35	65
1	3	3	3	558	1.09	0.76	1.29	35	36	52
1	2	2	2	1381	1.62	1.11	2.13	43	79	104
1	1	3	1	839	3.27	1.28	1.45	59	82	80
1	3	1	3	841	2.58	1.16	2.49	103	86	214
1	3	2	3	1110	1.66	1.16	2.42	67	82	95
1	1	1	1	*	1.35	1.11	1.67	68	29	73
1	1	2	1	750	1.71	0.54	1.10	105	*	50
2	2	1	3	1163	1.01	2.46	2.56	136	92	84
2	2	3	1	1279	2.41	3.23	2.70	71	65	63
2	3	3	2	1022	1.26	1.16	2.13	61	60	67
2	2	2	1	1127	2.42	1.84	3.09	94	80	92
2	1	3	3	891	1.70	2.28	1.00	20	83	84
2	3	1	1	*	3.73	1.75	1.23	205	86	89
2	3	2	2	756	2.03	2.06	2.94	*	115	88
2	1	1	2	1122	1.62	1.98	2.12	82	68	83
2	1	2	3	1007	1.29	1.14	1.64	50	42	56
3	2	1	1	1120	2.56	2.01	2.57	84	127	109
3	2	3	3	1216	2.70	1.77	1.88	63	71	95
3	3	3	1	968	2.13	1.56	1.77	67	103	106
3	2	2	3	938	3.09	1.87	1.74	92	100	167
3	1	3	2	815	1.00	1.26	0.86	84	110	104
3	3	1	2	*	1.23	0.84	*	89	86	*
3	3	2	1	835	2.94	2.46	2.25	88	115	87
3	1	1	3	1038	2.12	1.61	1.41	83	114	88
3	1	2	2	1067	1.64	2.34	2.36	56	84	83

Ap.Table 8.3. Individual data for OM intake ($gday^{-1}$) and concentrations of T_3 and T_4 (μgl^{-1}) in lambs given 0(1) isotyiocyanate(2) or nitrile(3) treatments - Experiment 6

Period	Sheep	Block	Treatment	OMI	T_3 Week 1	T_3 Week 2	T_3 Week 3	T_4 Week 1	T_4 Week 2	T_4 Week 3
1	1	3	1	*	1.45	0.97	1.42	98	58	77
1	1	1	1	671	1.68	2.05	1.92	81	42	43
1	2	3	2	514	1.23	1.44	2.44	66	53	45
1	3	3	3	907	1.77	1.63	2.66	67	64	65
1	1	2	1	498	1.21	0.85	1.28	52	30	19
1	2	2	2	378	1.15	1.21	1.67	73	55	50
1	1	4	1	606	1.03	1.03	1.50	36	37	62
1	3	1	3	565	1.59	1.59	1.87	114	75	87
1	3	4	3	*	*	*	*	*	*	*
1	3	2	3	639	1.59	1.59	2.11	90	82	79
1	2	4	2	210	*	*	*	49	37	65
1	2	1	2	*	*	*	*	*	*	*
2	1	3	2	344	1.42	1.86	1.30	77	47	38
2	1	1	2	548	1.92	2.56	2.46	43	33	25
2	2	3	3	530	2.44	1.98	1.13	45	25	20
2	3	3	1	881	2.66	1.98	2.03	65	32	38
2	1	2	3	510	1.28	1.14	0.33	19	9	3
2	2	2	1	340	1.87	1.42	1.46	50	41	46
2	1	4	3	601	1.50	1.44	1.75	62	59	48
2	3	1	1	455	1.87	1.75	1.87	87	86	81
2	3	4	2	*	*	*	*	*	*	*
2	3	2	2	532	2.11	1.99	2.12	79	64	54
2	2	4	1	390	1.44	0.93	1.57	65	41	29
2	2	1	3	*	*	*	*	*	*	*
3	1	3	3	509	1.30	1.91	1.07	38	20	14
3	1	1	3	267	2.46	2.75	1.41	25	28	37
3	2	3	1	*	1.13	1.34	1.05	20	9	13
3	3	3	2	819	2.03	1.73	1.74	38	24	30
3	1	2	2	385	0.33	0.39	0.24	5	5	4
3	2	2	3	464	1.46	1.56	0.93	46	32	33
3	1	4	2	708	1.75	2.44	1.57	48	37	46
3	3	1	2	413	1.87	2.94	2.10	81	79	94
3	3	4	1	*	*	*	*	*	*	*
3	3	2	1	600	2.12	2.50	1.06	54	31	28
3	2	4	3	501	1.57	2.11	0.73	29	35	29
3	2	1	1	*	*	*	*	*	*	*